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Effects of Appliance Type and Operating Variables on Woodstove Emissions. Volume 1. Report and Appendices A-C

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16. ABSTRACT

The report gives results of a project, in support of the Integrated Air Cancer Project (IACP), to provide data on the specific effects of appliance type and operating variables on woodstove emissions. Samples of particulate material and volatile organic compounds (VOCs) were collected. Particulate samples were analyzed for different organic fractions including specific polynuclear aromatic hydrocarbon (PAH) compounds. Inorganic matter on the filters was also analyzed. Results were calculated for pollutant concentrations, emission rates, and emission factors. Twelve test runs were conducted on a conventional stove, and two on a catalyst-equipped stove. Operating variables included fuel type (oak and pine), altitude (80 and 800 m), and burn rate (high and low). Test data were analyzed using analysis of variance and linear regression procedures. Although the data do not show strong statistical significance due to variability of results, some general trends do appear to be present, and conclusions can be drawn as to the effects of various operating variables on woodstove emissions. At the 99% confidence bound (CB), oak fuel reduced emissions of total PAH compounds relative to pine fuel. Emissions of carbon monoxide (CO) showed a significant decrease from low to high burn rates, and a small decrease when oak, rather than pine, is used.

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Stoves	Aromatic Polycyclic Hydrocarbons	Stationary Sources	13A	
Wood		Woodstoves	11L	
Combustion	Catalysis	Particulate	21B	07D
Particles	Carbon Monoxide	Volatile Organic Compounds	14G	07B
Organic Compounds			07C	

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Volume I

Report and Appendices A-C

by

Paul G. Burnet, James E. Houck, and Robert B. Roholt
OMNI Environmental Services, Inc.
Beaverton, Oregon 97005

EPA Contract: 68-02-4277

EPA Project Officer:
Robert C. McCrillis
Air and Energy Engineering Research Laboratory
Research Triangle Park, North Carolina 27711

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Abstract

This project was conducted in support of the Integrated Air Cancer Project (IACP) to provide data on the specific effects of appliance type and operating variables on woodstove emissions. Samples of particulate material and volatile organic compounds (VOC) were collected. Particulate samples were analyzed for different organic fractions, including specific polynuclear aromatic hydrocarbon (PAH) compounds. Inorganic matter on the filters was also analyzed. Results were calculated for pollutant concentrations, emission rates and emission factors. Twelve test runs were conducted on a conventional stove, and two runs were conducted on a catalyst-equipped stove. Operating variables included fuel type (oak and pine), altitude (80 meters and 800 meters) and burn rate (high and low).

Test data were analyzed using analysis of variance and linear regression procedures. Although the data do not show strong statistical significance due to variability of results, some general trends do appear to be present and conclusions can be drawn as to the effects of various operating variables on woodstove emissions. At the 99% confidence bound (CB), oak fuel reduced emissions of total PAH compounds relative to pine fuel. Emissions of carbon monoxide showed a significant decrease from low to high burn rates, and a small decrease when oak, rather than pine, fuel was used. The catalytic stove (with a used combustor) reduced emissions of carbon monoxide, but did not show significant reductions of total particulate material at the 99% CB. No altitude effects were noted at the 99% CB.

At the 95% CB, oak fuel reduced the concentration, emission rate and emission factor for many individual PAH compounds, and reduced the emission factor for total PAH compounds. Marginal decreases in benzene were also attributed to the use of oak, rather than pine, fuel.

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Section 1

Introduction

During the winter of 1986–87, the U.S. Environmental Protection Agency (EPA) conducted an emission measurement program in Boise, Idaho as part of the Integrated Air Cancer Project (IACP). This program was designed to identify the potential mutagenic impact of residential wood burning on ambient and indoor air. One aspect of this field sampling effort involved obtaining emission samples from chimneys serving wood burning appliances in Boise. As a companion to the field source sampling, a parallel project was undertaken in an instrumented woodstove test laboratory to quantify woodstove emissions during operations typical of Boise usage.

The purpose of this laboratory project was to quantify the effect of several variables on emissions from woodstoves so that operational conditions of stoves in the field could be inferred by existing data bases. The variables included: fuel species, burn rate and altitude (barometric pressure). A conventional woodstove, typical of many existing stove models in the Boise area, was used as the test appliance. Limited testing was also conducted on a catalytic woodstove. A modified half-factorial test matrix was used to obtain test results most useful to the IACP.

A woodstove dilution sampler (Woodstove Sampling System, or WS^2) was used to collect particulate samples, while a modified ambient sampler was used to collect aldehyde and volatile organic compound (VOC) samples. Particulate samples were analyzed for total mass, polynuclear aromatic hydrocarbons (PAH), total chromatographable organic compounds (TCO), and inorganic compounds. Concentrations of carbon monoxide, carbon dioxide and oxygen in flue gases were recorded. Samples of wood fuel and residual ash were analyzed for elemental composition.

Section 2

Conclusions

Fourteen tests were conducted on woodstoves to document the effects of stove appliance type and operating variables. Test variables included stove type (conventional and catalytic), fuel (oak and pine), altitude (80 meters and 800 meters) and burn rate (target rates of 1.6 kg/hr and 3.2 kg/hr). A modified half-factorial test matrix was used, with replicate tests under most conditions. Testing was conducted for particulate emissions, polynuclear aromatic hydrocarbons and volatile organic compounds. Particulate emissions were analyzed for semivolatile and condensible organics and for inorganic constituents.

Results of most tests were variable, with pollutant concentrations, emission rates and emission factors showing close agreement in some sample pairs and widely separated values in other pairs. As a result of this variability, defining the effect of specific test conditions was difficult. Analysis of variance (ANOVA) results showed relatively few "main effects," or statistically significant differences, for total pollutants. Most main effects occurred with carbon monoxide and individual PAH, VOC or elemental species. Oak, in comparison to pine, fuel was the variable which most frequently resulted in main effect decreases in pollutant concentrations, emission rates, and emission factors from the conventional stove. High burn rates, relative to low burn rates, also showed main effect decreases for many pollutants. The altitude variable did not show any main effects at the 99% confidence bound, and nominal or scattered results at lower confidence bounds. None of the variables resulted in main effects on the total particulate material emission rate, although a weak main effect was shown for the total particulate material emission factor at the 95% CB and the total particulate material concentration at the 90% CB.

The stove variable (catalytic stove versus conventional) showed a main effect decrease in CO (%) at the 99% CB and in CO (g/kg) at the 95% CB. A significant decrease (−452 mg/hr) in total PAH compounds was shown at the 95% CB, although the main effect was relatively weak (due to a high standard deviation).

The cold-start procedure used in this testing is thought to be a major factor in the variability of pollutant emission rates. The variability is apparently a real phenomenon, as was observed in recent field testing of woodstoves.[2] In the absence of statistically significant effects of stove variables, it may be appropriate to use the mean of emission values. Mean values should be used with upper and lower bounds to define probable emission rates and factors.

Total PAH emission rates measured in this testing were similar to previously reported results from the same conventional stove.[1] Emissions of volatile organic compounds (VOC) were lower than expected, based on previous testing.[1,3] Methane and ethylene represented the largest fraction of total VOC emissions. Benzene showed main effect decreases in concentration, emission rate, and emission factor when oak fuel was used rather than pine in the conventional stove.

The variability of test results indicates that several factors may affect stove emissions simultaneously. Isolating specific causes for particular emission rates may therefore be difficult.

Section 3

Recommendations

Based on the variability of emission rates observed in replicate tests, several modifications are recommended for future testing efforts. The sample size of future studies should be increased or the number of variables decreased. Fewer variables would allow more replicate tests to be conducted, which would better define representative emissions under given conditions. The cold-to-cold burn cycle used for this testing, in which sampling begins when a fire is lit, is thought to represent realistic stove operation. However, the cold-to-cold cycle is also a probable cause of the large variability observed in many test pairs. If cold-to-cold test cycles are used, more replicate tests should be made.

The woodstove sampler (WS^2) caused concerns over the representativeness of some samples due to occlusion of the sample inlet venturi. The venturi opening is about 3 millimeters in diameter. Even with heating tape maintaining a sample inlet temperature of about 120°C, heavy deposition of tarry material was noted on virtually all runs. On two tests, it was apparent that the venturi had been plugged during sampling and had to be opened with a rod. When the venturi is blocked, the accuracy of all emission measurements can be significantly affected. It is difficult with the current sampler design to determine when the venturi is becoming blocked. Modifications should be made to the WS^2 before any future testing, or another sampling method, such as EPA Modified Method 5, should be used.

The plugging of the venturi can also affect the accuracy of other sampling systems which pull off the WS^2 gas stream, such as the volatile organic compound (VOC) and aldehyde samplers used in this project. Until the potential for occlusion of the sample inlet is eliminated, other samplers should operate independently of the WS^2.

Careful recording of sampler operation time is necessary with the WS^2, VOC and aldehyde samplers used in this testing. For this reason, a pump run time counter is recommended for the samplers. This is especially important because of the 2 to 5 filter changes, and associated down time, during each test.

Stack flow rates are relatively constant when hot-to-hot burn cycles (such as those used in EPA Reference Method 28) are used. Cold-to-cold cycles can result in periods of high emissions when stack flow rates are fluctuating. A proportion sampler, or one that is relatively insensitive to flow fluctuations, may be more appropriate for future cold-to-cold burn cycle testing.

To ensure collection of valid aldehyde samples, lower sampler flows or tubes with greater sample capacity should be used. It is apparent from the exhaustion of the DNPH tubes that aldehyde emissions from woodstoves are significant. Future research should be planned accordingly.

All fires were started with no ash in the firebox, which permitted collection of residue at the completion of the run. This procedure may have contributed to variability of stove emissions. If collection of combustion residue is not required, future testing should be conducted using an ash bed in the firebox.

Section 4

Experimental Procedures

Variables

Due to the large number of variables which can potentially affect stove performance, a comprehensive, full-factorial testing plan was not realistic. Instead, a modified half-factorial testing program was developed which incorporated four major factors: burn rate, fuel species, altitude (barometric pressure) and stove type. The test matrix was designed to provide data most useful to the IACP. In most cases, replicate tests were performed to ensure the representativeness of samples. The test matrix is presented in Table 1 below:

Table 1. Modified Half-Factorial Testing Matrix

Sample Code	Stove	Fuel	Altitude	Burn Rate
SOLL-1 SOLL-2	Conventional (Scott) Conventional (Scott)	Oak Oak	Low Low	Low Low
SOLH-1 SOLH-2	Conventional (Scott) Conventional (Scott)	Oak Oak	Low Low	High High
SPLL-1 SPLL-2	Conventional (Scott) Conventional (Scott)	Pine Pine	Low Low	Low Low
SPLH-1 SPLH-2	Conventional (Scott) Conventional (Scott)	Pine Pine	Low Low	High High
SPHL-1 SPHL-2	Conventional (Scott) Conventional (Scott)	Pine Pine	High High	Low Low
SPHH-1 SPHH-2	Conventional (Scott) Conventional (Scott)	Pine Pine	High High	High High
EPHL-1 EPHH-1	Catalytic (Earth) Catalytic (Earth)	Pine Pine	High High	Low High

The sample code represents the variables used in testing. The first letter represents the stove type (Scott for conventional, Earth for catalytic), the second letter represents the fuel type (oak or pine), the third letter represents the test site elevation (low or high) and the fourth letter represents the burn rate (low or high). The number following the letter code denotes the first or second replicate test at the specified conditions. SOLL-1, for example, represents Scott stove (conventional)/oak fuel/low altitude/low burn rate/first replicate test run. Each of the variables is addressed individually below:

Stove

A primary objective of this testing program was to measure the stove performance of stoves thought to be typical of the Boise, Idaho region, where IACP field sampling was conducted in the winter of 1986-87. Research into "typical" or "conventional" stove models in Boise showed that no stove make or model was dominant.[4] Additional research showed the performance of conventional stoves to be a function of firebox size.[2,5] Therefore, since a large number of stove models were in use in Boise, but their performance was primarily a function of stove size, a single stove model was selected as representative of stoves used in the Boise region.

A "step top" freestanding stove manufactured by Scott Stove (an Idaho-based firm) was used for all conventional-stove tests. It had a steel firebox partially lined with firebrick with a 68 liter combustion chamber capacity. Air was supplied through a single manual "spin draft" control located in the lower third of the fuel loading door. The stove exhausted into a 15 centimeter (6 inch) diameter flue. The single wall steel chimney totaled 5.5 meters (18 feet) from the flue collar, or 6.25 centimeters (20.5 feet) from the base of the stove. Chimney height was identical at both the low and high elevation test sites.

Two tests were also conducted on a catalytic stove to gain information on the performance characteristics of catalytic stove technology. The catalytic stove was an Earth Stove 1000 C, with a Corning "Long Life" catalytic combustor. It was not determined whether the emissions from this stove are representative of all catalytic stoves, but the stove's size and design are consistent with many catalytic stoves currently being used. The combustor had about 6,000 hours of use at the time of testing, as this stove had been used in prior EPA research of combustor longevity. The 1000 C had a firebox capacity of 60 liters.

Fuel

Two fuel species were used in the testing program. Eastern red oak from North Carolina was used for four tests, all of which were conducted at the low elevation test site. Moisture content of the oak ranged between 27.2% and 42.4% (dry basis) and averaged 33.2%. Lodgepole pine from the Boise area was used for a total of four low elevation tests and six high elevation tests. The pine averaged 24.3% moisture (dry basis), ranging from 18.0% to 35.1%. Fuel moistures were intended to represent seasoned firewood. The oak had a slightly higher moisture content, as the hardwood dries slower and equilibrates at a higher moisture content than the pine. All fuel was split cordwood with bark intact. Fuel size was held relatively constant, with each piece having a cross-sectional area of 65 to 130 square centimeters.

Altitude

Testing was conducted at two elevations. The low elevation testing was performed at an altitude of 80 meters (258 feet) in the woodstove certification laboratory facilities of OMNI Environmental Services located in Research Triangle Park, North Carolina. The high elevation testing was conducted at 800 meters (2620 feet) in the woodstove development laboratory of the Buck Stove Company in Spruce Pine, North Carolina. This site was selected to approximate the elevation of Boise (915 meters, 3000 feet) where ICAP field measurements of woodstove emissions had been made.

Standard barometric pressure is 1013 millibars (29.92 inches mercury) at sea level. Barometric pressure changes in a linear fashion with altitude; standard pressure is 1003 millibars (29.62 inches mercury) at 80 meters and 913 millibars (26.97 inches mercury) at 800 meters. Actual barometric pressure is affected by meteorological conditions; the range of actual pressures was 1006 millibars to 1018 millibars at the low elevation test site and 926 millibars to 935 millibars at the high elevation site.

Burn Rate

High and low burn rates were used in the testing program. Burn rates were selected to represent average burn rates thought to be typical of the Boise region.[2,6] The low burn rate target (1.6 kilograms per hour [dry]) was equivalent to a heat output of about 4.4 kilowatts from a woodstove, which is typical of the average heating requirements in Boise. The high burn rate target (3.2 kg/hr [dry]) was intended to provide data on burn rates which may be commonly used to heat a house which has been cool, simulating start-up burning conditions.

Constants

The variables listed above were selected as factors with a high probability of affecting emission rates. Other factors, which may also affect stove performance, were held constant as much as possible. These factors are listed below:

Fuel Moisture

As mentioned above, moisture content of the oak averaged 33.2% (dry basis) and 24.3% for the pine. These represent average moisture contents taken in random measurements of 10% of the fuel pieces burned during testing. The moisture content of green, unseasoned wood can range much higher, and wood stored in a heated indoor area can equilibrate at moisture contents well below 20%. The moisture content of fuel for this testing was kept as uniform as possible. Fuel moisture was measured using a Delmhorst RC-1C moisture meter and an oven drying method (ASTM D2016) on fuel samples in the laboratory.

Fuel Size

Fuel size can affect emission rates due to differences in the surface area-to-volume ratio. Small pieces have a higher ratio and can release volatile components of the fuel more quickly than larger pieces. Fuel size was kept as constant as possible, averaging 65 to 130 square centimeters (10 to 20 square inches) in cross section. Piece length was approximately 41 centimeters (16 inches).

Fuel Load

Based on woodstove field testing studies[2,6] an average fuel load of 0.088 kg/l (5.5 lb/ft^3) was used for all testing. This is somewhat smaller than the 0.112 kg/l (7.0 lb/ft^3) fuel load used in EPA woodstove certification testing[7] but was more representative of the fuel loads typically seen in the field. The Scott (conventional) stove was started with a total fuel load of about 6.0 kg (13.2 lb), which is equivalent to a 0.088 kg/l fuel load density in the 68 liter firebox. When the fuel had burned down to 1.8 kg, more fuel was added to bring the fuel load back up to a total fuel load of 6.0 kg.

The catalytic Earthstove, with a firebox volume of 60 liters, was charged with fuel loads of 5.3 kg.

Burn Cycle

Stove testing conducted in accordance with EPA Method 28 uses a "hot start," in which a hot glowing bed of embers is used to ignite the test fuel load, thereby minimizing test-to-test variability.[7] However, field data indicates that many homes in moderate climates do not burn their stoves continuously.[2,6] A "cold start" procedure was therefore considered more representative of Boise woodburning practices.

Prior to starting the test, the stove was burned for at least two hours at the same air setting to be used during testing to precondition the stove and flue. This step was taken to reduce effects of existing creosote deposits in the stove and flue which could be revolatilized during testing and result in non-representative samples. The stove was allowed to cool after the preconditioning and prior to testing. The flue was thoroughly brushed to remove accumulated creosote. Ash and combustion residue were removed from the stove, and the firebox was vacuumed.

At the start of each test, a small fire was built with four sheets of newspaper, 2.0 kg of finely split kindling (of the same species as the fuel being tested) and four small pieces of fuel (26 cm^2 to 52 cm^2 in cross-section).

Four minutes after lighting the fire (T + 4 minutes), the stove door was closed but the air setting left in the full open position. At T + 10 minutes, test fuel was added to bring the total fuel load up to the specified mass. The primary air control was set in a position to yield the desired burn rate.

The stove was refueled when the fuel load dropped to 1.8 kg. Wood was added to bring the total fuel load up to the specified load (5.3 kg for the Scott and 6.0 kg for the Earthstove). Burning and refueling were continued for a minimum of 6 hours. Testing was ended when 5% of the total test fuel mass remained, and the flue gas temperature dropped below 65° C (150° F).

Section 5

Sampling and Analytical Methods

Sampling Methods

The sampling methods used in this project were selected to duplicate, as closely as possible, the equipment and procedures used for IACP sample collection in Boise, Idaho. All sampling began when the fire was lit and continued through the burn cycle. Details of the sampling equipment are provided below. The overall test arrangement is shown in Figure 1.

Particulate Material Sampling

Particulate samples were collected using the Woodstove Dilution Sampling System, or WS^2, which was used in the Boise IACP work.[8] The WS^2 draws a portion of flue gas out of a chimney at a constant (nonproportional) rate and mixes the sample gas with filtered dilution air (Figure 2). Particles are captured on 20 cm by 25 cm (8" by 10") acid-cleaned Pallflex filters. Organic compounds which pass through the filter are captured by a cartridge containing about 200 grams of XAD-2 resin. Flows through the sampler are measured in three locations:

1. Sample flow – The pressure differential across a venturi (between the probe and dilution chamber) is used to measure flue (sample) gas flow into the sampler (Figure 3).

2. Dilution air flow – The pressure differential across a sharp-edged orifice is used to measure dilution air flow into the dilution chamber.

3. Exhaust flow – The pressure drop across a sharp-edged orifice is used to measure total gas flow through the filter and XAD-2 cartridge.

All pressure values are measured with Dwyer pressure transducers.

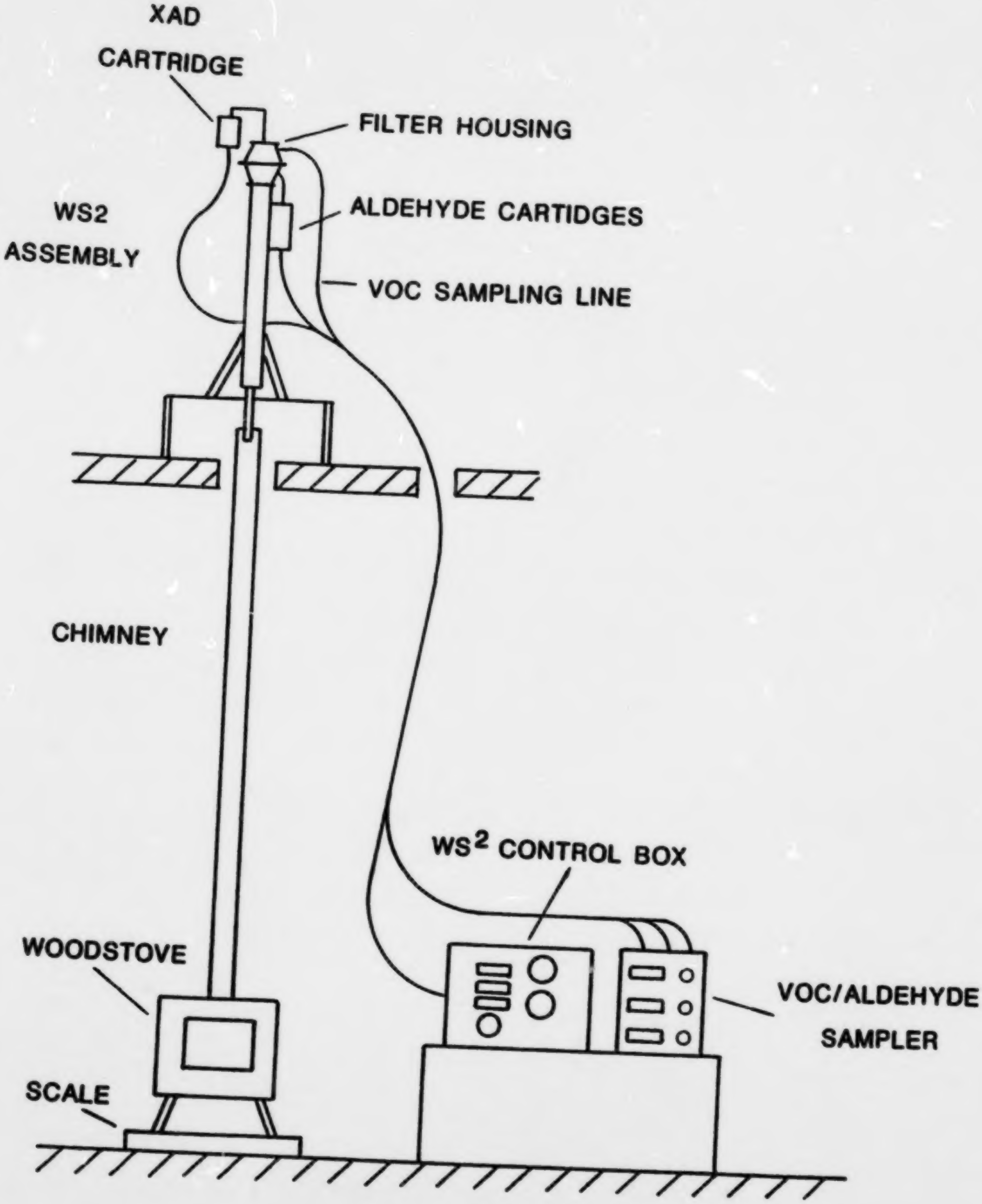
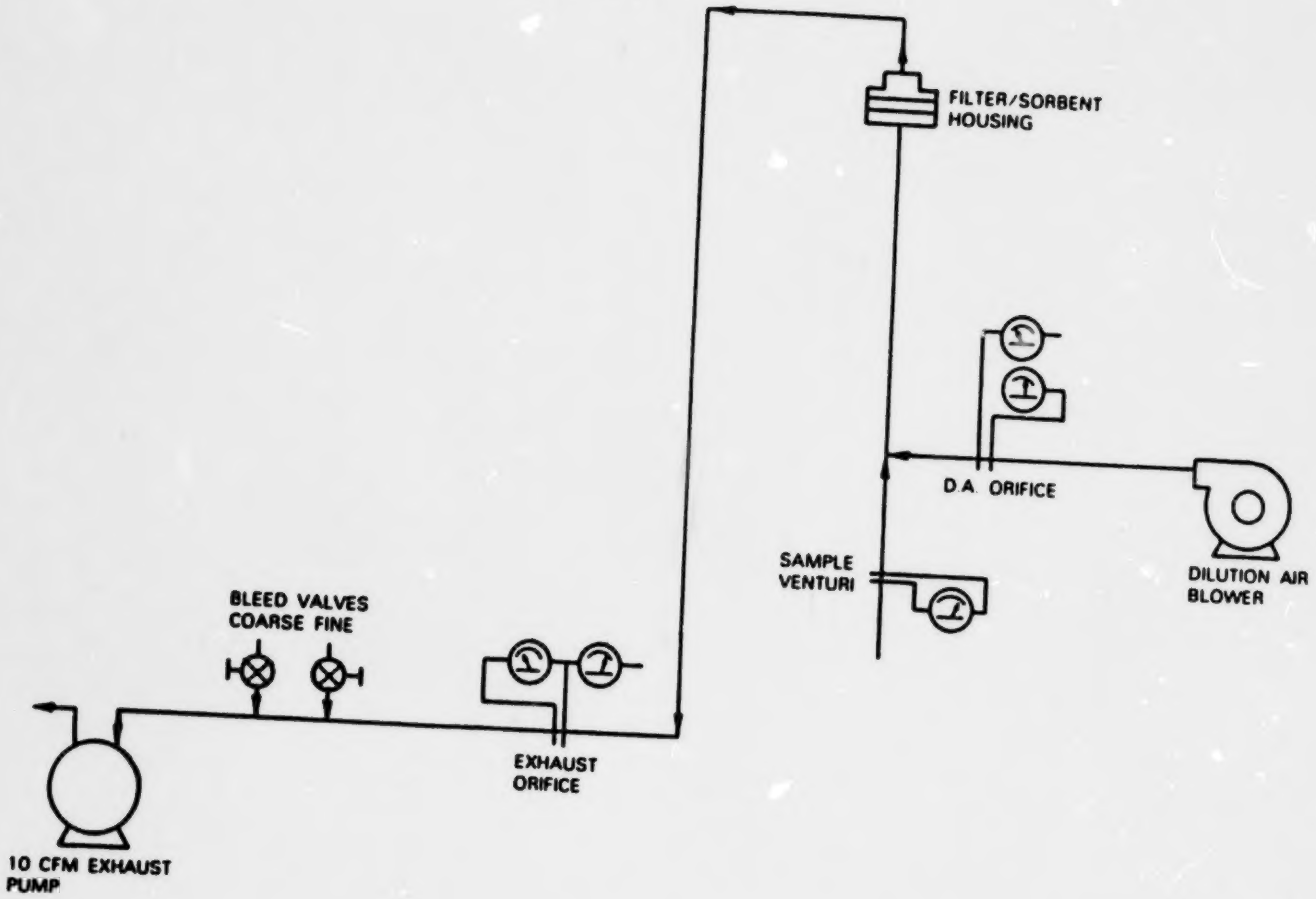

XAD
CARTRIDGE
FILTER HOUSING
WS2
ASSEMBLY
ALDEHYDE CARTIDGES
VOC SAMPLING LINE
CHIMNEY
WS^2 CONTROL BOX
WOODSTOVE
VOC/ALDEHYDE
SAMPLER
SCALE

Figure 1. Schematic of WS^2 sampler with VOC and Aldehyde Attachments.


FILTER/SORBENT
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D.A. ORIFICE
SAMPLE
VENTURI
DILUTION AIR
BLOWER
BLEED VALVES
COARSE FINE
EXHAUST
ORIFICE
10 CFM EXHAUST
PUMP

Figure 2. Schematic of WS^2 sampler (source: Ref. 10).

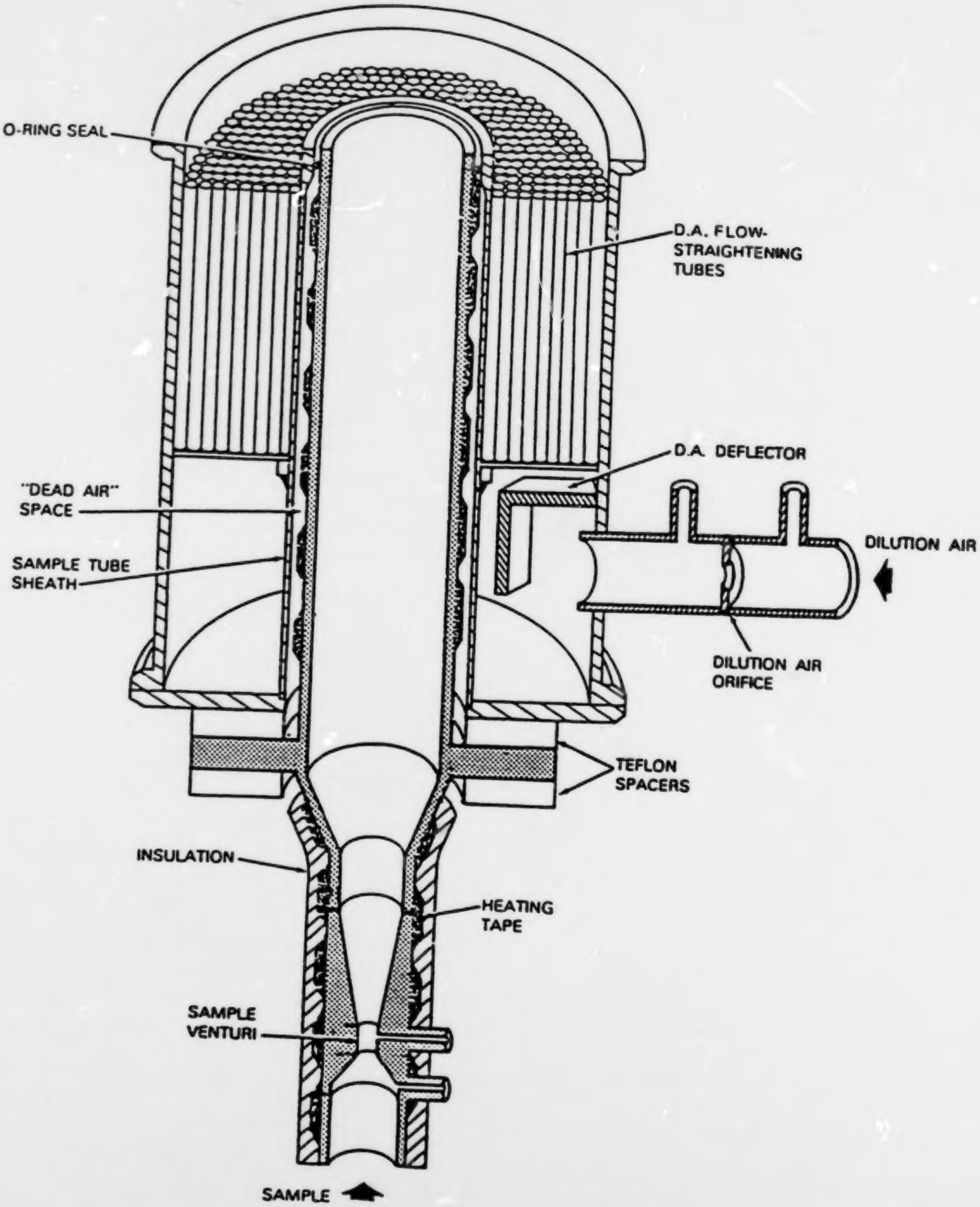
O-RING SEAL
D.A. FLOW-STRAIGHTENING TUBES
D.A. DEFLECTOR
"DEAD AIR" SPACE
DILUTION AIR
SAMPLE TUBE SHEATH
DILUTION AIR ORIFICE
TEFLON SPACERS
INSULATION
HEATING TAPE
SAMPLE VENTURI
SAMPLE

Figure 3. Detail of WS^2 inlet section (source: Ref. 10).

A constant sampling rate was maintained by adjusting exhaust and dilution air blowers to compensate for increased filter loadings. When the pressure drop across the filter became too high, the filter was changed. This procedure usually required five to ten minutes. Two to five filter changes were required for each test. Total sample volume was calculated from the flow rate measured at the sample inlet and the total sample period. Down time for filter changes was subtracted from the total sampling time.

After removal from the sampler, filters were placed in aluminum foil and stored at ≤ 0°C. At the completion of testing, XAD-2 resin cartridges were capped and placed in Teflon bags, thermally sealed, and also stored at ≤ 0°C. All surfaces in the WS^2 exposed to sample gases were rinsed and brushed with dichloromethane and methanol. The solvent/sample mixtures were placed in acid-cleaned amber glass bottles with Teflon-lined lids and stored at ≤ 0°C. Runs 1 through 8 received the methanol rinse first, and Runs 7 through 16 received the dichloromethane rinse first. All samples were transferred to an EPA contract laboratory in Research Triangle Park, North Carolina within several days of testing, where storage at ≤ 0°C continued until analysis. Samples from the WS^2 were used to determine concentrations of total particulate material; condensible (gravimetric) and semivolatile (total chromatographable organic) fractions; and polynuclear aromatic hydrocarbons (PAH). The elemental composition of the particulate catch was also determined and reported. Bioassay testing of the particulate samples was conducted, although results were not available for inclusion in this report.

Volatile Organic Compounds (VOC) Sampling

Concentrations of volatile organic compounds in woodsmoke were measured by obtaining integrated samples over the test period. Sampling equipment was provided by EPA. A sample was drawn from a port in the WS^2 between the filter and XAD-2 canister and drawn through a heated Teflon "roughing" line. From this line, a smaller fraction was pumped into an evacuated six-liter SUMMA-polished canister at a constant rate. Sampling continued throughout the test period. At the completion of testing, canisters were shipped by air freight to the Laboratory for Atmospheric Research, Washington State University, Pullman, Washington, where they were analyzed within 36 hours by gas chromatography.

Aldehydes

Concentrations of aldehydes in woodsmoke were measured by drawing a sample through DNPH-treated tubes. A sample was drawn from a port in the WS^2 immediately before the filter, through a DNPH collection tube in a heated chamber. Dual aldehyde samplers were used. One channel was operated with a sample flow rate half that of the other channel in an effort to prevent DNPH exhaustion and breakthrough. Sampling rates were maintained by mass flow controllers. Aldehyde sampling equipment was provided by EPA. Aldehyde sample tubes were stored in refrigerated glass tubes prior to and immediately after sampling and were delivered to EPA for analysis within several days of testing.

Carbon Monoxide

Carbon monoxide concentrations in woodsmoke were measured using an Infrared Industries Model IR-732 nondispersive infrared analyzer. Readings were recorded at ten-minute intervals throughout the burn cycle. Carbon dioxide and oxygen values were also recorded at ten-minute intervals.

Other Parameters

Stack flow was calculated using EPA Method 5H.[5] Burn rate was determined by an electronic platform scale, on which sat the entire stove and chimney. Ash residue was collected from the firebox at the completion of a test burn and placed in glass jars. Sawdust samples were collected from fuel pieces when test blocks were cut for oven drying, and also placed in glass jars prior to analysis.

Analytical Methods

Unless otherwise noted, sample preparation and analysis procedures for samples from the WS^2 were performed by the Acurex Corporation under contract to EPA.

Preparation of Sampling Media

Filters

All WS^2 filters were Pallflex filters, acid washed and tared before all sampling. Filters were soaked in a bath of 0.05% (1:200 reagent grade concentrated) nitric acid for 24 hours. The dilute acid was exchanged for fresh solution and the filters were soaked overnight. The bath was then changed to deionized water and the filters were soaked overnight. This procedure was done twice. The filters were dried in an oven at 110°C. Each filter was wrapped in aluminum foil and labeled individually. The wrapped filters were desiccated overnight and tared before use. The filters were tared on a Mettler top loader balance. This procedure was necessary because the filters were too large to fit within the compartments of available analytical balances and was considered acceptable due to the high expected sample loading.

Adsorbent Resin

XAD-2 resin was cleaned prior to use as per the large scale cleaning process AEERL/ROP#25. This procedure consists of the extraction of impurities by sequentially pumping methanol and dichloromethane through the resin. The remaining solvent is removed from the resin by evaporation with a stream of nitrogen.

Sample Preparation

Filters

All sample filters were desiccated and weighed to determine total particulate capture. All of the filters used for a single sampling run were then composited and transferred to a single beaker. Dichloromethane was added, and the beaker was covered with aluminum foil to reduce evaporation and contamination. For each filter making up a composite sample, 100 milliliters of dichloromethane was used. After 15 minutes of shaking in an ultrasonic bath, the dichloromethane extract was transferred to a 2 liter round bottom flask. This process was repeated until a total of 400 ml per filter had been used. The composited dichloromethane extract was concentrated by evaporation in a modified Kuderna-Danish apparatus and made up to a known volume. Concentrated extracts were transferred to 4 dram glass vials for storage prior to analysis. The vials were sealed with Teflon-lined, septa-equipped screw caps. The joint of the vial and cap was wrapped with Teflon tape. Concentrated extracts were stored cold. Filters were returned to OMNI for subsequent elemental analysis.

Adsorbent Cartridges

XAD-2 samples were solvent-extracted in accordance with a pump-through procedure. Each cartridge was extracted with one liter of dichloromethane. Each fraction was concentrated by evaporation in a modified Kuderna-Danish apparatus, then made up to a known volume in a volumetric flask. Concentrated extracts were transferred to 4 dram glass vials for storage prior to analysis. The vials were sealed with Teflon-lined, septa-equipped screw caps. The joint of the vial and cap was wrapped with Teflon tape. Concentrated extracts were stored cold.

Analysis

Total Capture

This analysis was applied to all filters. Each filter was transferred to a desiccator upon its return from the field. After a minimum of 24 hours in the desiccator the filter was weighed. The total capture value for each filter was calculated as the difference between the final weight and the tare weight. The total capture per run was calculated as the sum of the values from the individual filters plus the gravimetric and total chromatographable organic fractions from solvent rinses of the sampler and XAD-2 resin extracts.

Gravimetric (Condensible)

The "micrograv" procedure was followed for the analysis of these samples. The "grav" fraction represents organic compounds with boiling points greater than 300°C. A 0.25 ml aliquot of extract was used in the micrograv pan. A second "end test" (0.03 milligram gross difference in consecutive weighings or 1% relative net difference) was added in recognition of the high levels expected in this test.

Two tared micrograv pans were prepared for each sample. A 0.25 ml aliquot of extract was added to each pan. The pan plus sample was weighed at 24-hour intervals until the end test was passed. Between weighings the pans were stored in a desiccator over activated carbon and silica gel.

The net weight per pan was calculated by subtracting the tare weight. The net weight was multiplied by four to obtain the extract concentration in units of grams per milliliter. The mass per sample was obtained by multiplying the concentration by the total extract volume.

Finally, a QC test was applied to the two analyses. A mean and relative standard deviation were calculated from the duplicate analyses. If the percent relative standard deviation (percent RSD) exceeded 15% for a quantifiable sample, the sample was repeated.

This procedure was followed for filter, probe rinse and XAD-2 extract samples.

Total Chromatographable Organics (Semivolatile)

TCO compounds are defined as organics with boiling points between 100 and 300°C. The TCO determinations were made using a Hewlett-Packard 5880 gas chromatograph (GC) equipped with a Level 4 terminal. An aliquot of each sample extract was sealed in a glass autosampler vial with a Teflon-lined crimp-seal cap. The samples were then loaded into the sample tray of the autosampler. Sample identification and other pertinent information was entered for each sample from the terminal. Samples were injected into a 3.0 meter by 0.25 millimeter fused-silica capillary column coated with SPB-1 as the stationary phase. Column temperature at injection was 40°C. At three minutes following injection the column oven temperature was activated, initiating a heating cycle of 8°C per minute to a final temperature of 250°C. The total run time was 45 minutes.

The column was connected to a flame ionization detector (FID) that produced a response approximately proportional to the weight of organic material present in the sample. Internally, this signal was amplified and digitized at a sampling rate of 30 data points per second, and baseline corrected. The operating system then used a sophisticated algorithm to determine the validity of the current data point. The algorithm defined valid data based upon the first derivative and peak width as a function of retention time. Valid data was stored electronically until each analytical run was completed. At that point the TCO program summed together all valid data due to peaks with retention times between those of the marker compounds heptane and heptadecane. After duplicate runs of each sample, the TCO program used storage parameters to calculate TCO mass per sample and simple statistics using the replicate results.

VOC

Hydrocarbon concentrations for species in the C_2–C_5 molecular weight range were determined with a Perkin Elmer 900 gas chromatograph. A packed capillary (20' by $^1/_{16}$") column containing Durapak n-Octane/Porasil C was used to separate light hydrocarbons. The carrier gas (He) was operated at a flow of 5 ml/min and temperature-programmed from -50°C to 80°C at 24°/minute.

Analysis of hydrocarbons in the C_5–C_8 molecular weight range was performed on a Hewlett-Packard 5880 gas chromatograph. A 30 meter DB–1 fused silica column was used in the HP 5880 in conjunction with the same type of cryogenic concentration procedure used for the light hydrocarbons. The higher molecular weight hydrocarbons were determined through retention time comparisons and mass spectral analysis.

Inorganics

After extraction, proportional fractions of filters were digested in a mixture of nitric and hydrochloric acids. Solutions were then scanned for heavy metals using a Jarrell Ash Model 975 inductively coupled argon plasma (ICAP) spectrograph.

Section 6

Results and Discussion

Test Results

Fuel Characteristics and Test Conditions

The test fuel was analyzed to characterize differences between pine and oak. Table 2 lists proximate and ultimate analysis results. Table 3 shows the elemental composition of the two fuel types, and Table 4 lists fuel moistures. Table 5 shows the elemental composition of combustion residue and ash remaining in the firebox after testing.

The oak fuel had a significantly higher ash content than the pine. The oak averaged 4.22% ash compared to 0.64% for the pine. The volatile fraction of the pine averaged almost 4.5% higher than the oak. The pine fuel also had a heat content about 7% higher than the oak.

The elemental composition of the fuels was quite variable, both among pine samples and between pine and oak. Based on the observed variability, it is difficult to determine whether differences were due to normal variability or to consistent differences between species of wood.

Fuel moisture was measured by moisture meter (Delmhorst RC-1C) and by oven-drying wood blocks (ASTM D2016). Agreement between the two methods was good, averaging ±0.9% (absolute) moisture. Oak fuel averaged about 33%, while the pine averaged about 26% (dry basis, oven method).

The elemental composition of combustion residue and ash left in the firebox after the completion of testing was relatively constant (Table 5). Run 13 on pine showed concentrations of magnesium in residual ash to be about a factor of 10 higher than other runs. This is thought to be an anomaly, as other pine samples show much lower values. The phosphorus (as PO_4) content of pine ash appears to be about two to three times that of oak ash. Other elemental values appear to be variable among similar fuels and between fuels.

Table 2. Wood-Fuel Proximate/Ultimate Analyses[a]

Fuel Type[c]	Test Run Numbers	Sample ID[d]	Composition – Percent by Weight[b]									HHV (10^{6}J/kg)[f]
			Moisture (DB)[e]	Ash	Total Carbon	Fixed Carbon	Volatile Fraction	Hydrogen	Oxygen	Nitrogen	Sulfur	
Oak	(1,2,3,4)	O1–LA O1–LB O1–LC	18.1 17.8 17.6	3.85 4.17 4.64	49.89 49.61 49.64	13.57 14.46 14.28	82.58 81.37 81.08	5.75 5.67 5.62	39.81 39.81 39.31	0.59 0.63 0.61	0.11 0.11 0.18	18.987 18.957 19.154
		Mean	17.8	4.22	49.71	14.10	81.68	5.68	39.64	0.61	0.13	19.034
		S.D.(S)[g]	0.3	0.40	0.15	0.47	0.80	0.07	0.29	0.02	0.04	0.107
Pine	(5,6,7, 8,9)	P1–L P1–H	13.2 12.9	0.75 0.72	51.93 51.95	14.76 12.69	84.49 86.59	5.97 6.00	40.84 40.50	0.46 0.52	0.05 0.31	20.431 20.336
		Mean	13.05	0.74	51.94	13.73	85.54	5.99	40.67	0.49	0.18	20.385
	(10,12,13, 14,16)	P2–L P2–H	15.6 13.6	0.47 0.60	52.89 53.09	12.33 13.68	87.20 85.72	6.05 6.62	40.11 39.71	0.44 0.41	0.04 0.17	20.792 20.552
		Mean	14.6	0.54	52.99	13.01	86.46	6.04	39.91	0.43	0.11	20.673

a – Proximate/ultimate analyses were conducted on composited sawdust samples collected from at least 10% of the fuel logs burned in testing. Sawdust samples were obtained with a handsaw (to minimize effects), with cuts in the middle of the fuel piece. Analyses were conducted by a commercial laboratory using the following reference methods:

moisture – ASTM D2016
ash – ASTM D1102
carbon – ASTM D3178
volatile matter – ASTM D3175
hydrogen – ASTM D3178
oxygen – by difference
nitrogen – ASTM D3179
sulfur – ASTM D4239
HHV – ASTM D2015

b – Dry basis. The constituents listed, excluding moisture, fixed carbon, and volatiles, sum to 100%.

c – Pine fuel was lodgepole pine from Idaho, which is used extensively in the Boise region for firewood. Oak fuel was eastern red oak from North Carolina. All P1 samples were from the same tree.

d – "L" designates fuel used for low-elevation testing, while "H" designates fuel used in high-elevation testing. "A," "B," and "C" codes on the oak samples identify the three replicate samples used as an indicator of the precision of the testing methods.

e – Moisture is reported on a dry basis. Sawdust samples were routinely lower in moisture than block samples; values presented here are considered not representative of actual fuel moisture.

f – Higher Heating Value, reported in million joules per kilogram.

g – Standard deviation (S)

Table 3. Wood-Fuel Elemental Composition (ppmm)[a]

Fuel Type	Ash	Al	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni	PO_4	K	Na	Sr	Ti	V	Zn
Pine 1-A	0.94	326	43.2	BDL	7.75	BDL	6203	12.6	BDL	1.38	375	29.7	578	127	2.31	470	201	386	30.6	4.98	BDL	27.5
Pine 1-B	0.88	275	37.1	BDL	6.15	BDL	5716	3.3	BDL	1.21	318	10.9	565	114	BDL	465	164	439	28.0	5.18	BDL	21.7
Pine 1-C	0.86	275	38.4	BDL	6.52	BDL	5410	BDL	BDL	1.43	367	BDL	556	115	BDL	440	158	398	27.8	3.00	BDL	24.9
Mean	0.89	292	39.6	-	6.81	-	5776	5.3	-	1.34	353	13.5	566	119	0.77	458	174	408	28.8	4.39	-	24.7
Standard Deviation (S)	0.04	29	3.2	-	0.84	-	400	6.5	-	0.12	31	15.0	11	7	1.33	16	23	28	1.6	1.21	-	2.9
Pine 2	1.00	73	12.1	BDL	3.67	BDL	1570	5.9	1.39	18.60	2830	5.7	195	97	12.20	129	324	74	8.1	2.90	BDL	19.2
Pine 3[b]	0.65	88	12.7	BDL	4.72	BDL	1895	BDL	BDL	1.62	256	BDL	188	59	BDL	246	322	13	9.8	0.72	BDL	11.0
Oak 1	2.69	376	126	BDL	10.10	BDL	18268	BDL	BDL	4.20	687	BDL	358	370	6.18	480	548	775	145.0	15.20	0.61	4.94
Detection Limit	-	8.0	0.05	0.15	0.50	0.5	0.5	1.5	1.00	0.75	1.5	4.0	0.05	0.15	1.5	20.0	0.5	5.0	0.05	0.3	0.50	0.75

a - Samples were analyzed by inductively-coupled argon plasma (ICAP) spectroscopy at a commercial laboratory. All results are reported as micrograms per gram (parts per million mass) of dry sample. Elements listed by symbol are identified below:

Al - aluminum
Ba - barium
Be - beryllium
B - boron
Cd - cadmium
Ca - calcium
Cr - chromium

Co - cobalt
Cu - copper
Fe - iron
Pb - lead
Mg - magnesium
Mn - manganese
Ni - nickel

PO_4 - phosphorus
K - potassium
Na - sodium
Sr - strontium
Ti - titanium
V - vanadium
Zn - zinc

BDL - below detection limit.

Elements which were not found above detection limits include:

		Detection Limit (micrograms per gram)
Sb	- antimony	8.0
As	- arsenic	15.0
Bi	- bismuth	25.0
Mo	- molybdenum	2.0
Se	- selenium	—
Ag	- silver	—
Sn	- tin	1.5

b - Results are averages of two samples of the same lot of wood. One sample was collected at the "high altitude" lab, and the other was collected in the "low altitude" lab.

Table 4. Fuel Moisture

Fuel Type	Test Run Numbers	Block ID	Meter[a] (% DB)	Oven Method	
				(% DB)[b]	(% WB)[b]
Oak	(1,2,3,4)	1	29.1	31.9	24.2
		2	32.8	31.5	24.0
		3	36.1	30.1	23.1
		4	36.3	33.6	25.2
		5	35.2	42.4	29.8
		6	33.8	30.2	23.2
		7	38.3	38.9	28.0
		8	38.7	37.7	27.4
		9	30.2	27.2	21.4
		10	30.2	27.7	21.7
		Mean	34.1	33.1	24.8
Pine	(5,6,7, 8,9,10)	1	21.6	20.8	17.2
		2	18.9	18.4	15.6
		3	18.7	18.0	15.3
		4	18.8	18.8	15.8
		5	21.3	21.2	17.5
		3H	30.0	35.1	26.0
		4H	24.1	23.0	18.7
		5H	31.1	34.7	25.8
		6H	20.5	21.7	17.8
		7H	18.7	19.9	16.6
		8H	18.9	19.7	16.4
		9H	21.4	24.2	19.5
		Mean	22.0	23.0	18.5
	(10,12, 13,14,16)	10H	25.4	26.3	20.8
		11H	28.4	28.1	21.9
		12H	24.7	27.6	21.6
		13H	23.8	24.2	19.5
		6	22.6	21.8	17.9
		7	29.0	31.4	23.9
		8	26.2	24.9	19.9
		9	24.2	24.9	19.9
		Mean	25.5	26.2	20.7

a – Moisture content of fuel was measured using a Delmhorst RC-1C moisture meter.

b – Fuel blocks were dried in an oven at 105°C following ASTM D2016. Moisture is calculated as:

$$\text{dry basis (DB)} = \frac{(\text{mass wet} - \text{mass dry})}{\text{mass dry}}$$

$$\text{wet basis (WB)} = \frac{(\text{mass dry} - \text{mass wet})}{\text{mass wet}}$$

Table 5. Ash Elemental Composition (ppmm)[a]

Run Number	Fuel Type	Sample Code[b]	Al	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	PO_4	K	Ag	Na	Sr	Ti	V	Zn
1	Oak	SOLL-1	3200	1880	0.22	121	0.63	169000	4.8	14.0	58.4	5680	6.3	5800	6580	BDL	4.50	6330	31000	BDL	608	1340	197	7.5	58.0
3A	Oak	SOLL-2	4040	2080	0.24	162	0.68	220000	5.8	14.3	79.3	3920	8.8	7350	6080	BDL	5.75	8730	35200	BDL	950	1580	233	8.5	138
3B	Oak	SOLL-2	3880	2010	0.24	149	0.75	207000	5.0	14.0	76.5	3810	9.0	7050	5750	BDL	5.50	8150	36600	BDL	805	1530	222	10.0	45.8
3C	Oak	SOLL-2	4020	2080	0.25	173	0.93	209000	4.5	14.0	79.3	3510	9.0	7330	5850	BDL	6.00	8750	30800	BDL	858	1520	246	8.8	47.0
3 Mean	-	-	3980	2057	0.24	161	0.79	212000	5.1	14.1	78.4	3747	8.9	7243	5893	BDL	5.75	8543	34200	BDL	871	1543	234	9.1	76.9
3Std.Dev.	-	-	87	40	0.01	12	0.13	7000	0.6	0.2	1.6	212	0.1	168	169	BDL	0.25	341	3027	BDL	73	32	12	0.8	52.9
2	Oak	SOLH-1	6100	1970	0.18	127	L	210000	5.5	11.0	56.2	7600	5.0	5900	5650	BDL	5.00	6300	22900	BDL	620	1630	349	14.0	30.0
4	Oak	SOLH-2	2460	2600	0.27	181	L	305000	3.5	12.5	75.0	1600	5.5	8350	8100	BDL	3.30	9100	48100	BDL	570	2240	84	3.3	27.8
6	Pine	SPLL-1	7150	1550	BDL	200	3.90	192000	6.5	2.6	105.0	1990	17.0	30800	5700	BDL	2.85	23800	58000	BDL	1310	1160	86	1.3	655
14	Pine	SPLL-2	7130	1440	BDL	250	6.25	193000	14.3	4.4	101.0	28200	11.0	28200	8150	BDL	16.50	21800	45700	15.0	1140	1190	57	1.1	1060
5	Pine	SPLH-1	5620	1220	BDL	159	3.75	160000	5.0	2.3	91.4	1430	35.0	21400	3940	BDL	2.65	15300	43200	BDL	1110	905	109	1.4	417
16	Pine	SPLH-2	7580	1800	BDL	260	1.18	227000	8.8	3.9	111.0	2690	5.5	34500	9830	2.2	5.50	24700	49100	11.0	1160	1390	89	BDL	449
9	Pine	SPHL-1	7850	1290	BDL	221	4.45	197000	12.0	3.5	93.0	4440	14.0	28200	6250	BDL	3.25	18700	46600	14.5	1850	1100	146	3.2	1150
10	Pine	SPHL-2	8800	1430	BDL	224	2.68	209000	11.8	3.6	102.0	7000	7.5	27900	7100	2.9	4.25	21300	46200	14.5	1810	1200	124	2.2	920
7	Pine	SPHH-1	9050	1390	BDL	273	0.73	214000	11.5	4.4	88.3	3100	8.5	38600	10200	2.6	4.50	23700	48700	8.3	1440	1450	112	3.2	590
8	Pine	SPHH-2	9280	1650	BDL	252	0.68	214000	14.5	4.0	120.0	5060	6.5	41700	7680	2.9	4.00	28400	55000	6.8	2620	1390	148	5.2	480
12	Pine	EPHL-1	7950	1140	BDL	285	68.50	219000	18.3	4.4	205.0	4450	19.0	30000	8900	2.9	15.50	22000	46700	18.5	1410	1330	54	1.7	1660
13	Pine	EPHH-2	5850	1190	BDL	185	14.0	160000	13.0	2.9	80.5	2120	12.3	214000	6680	3.1	5.50	16500	34100	12.8	1170	980	82	1.1	650

a - Samples were analyzed by inductively-coupled argon plasma (ICAP) spectroscopy at a commercial laboratory. All results are reported as micrograms per gram (parts per million mass) of dry sample. Reported values were corrected for field blanks.

Al - aluminum
Ba - barium
Be - beryllium
B - boron

Cd - cadmium
Ca - calcium
Cr - chromium
Co - cobalt

Cu - copper
Fe - iron
Pb - lead
Mg - magnasium

Mn - manganese
Mo - molybdenum
Ni - nickel
PO_4 - phosphorus

K - potassium
Ag - silver
Na - sodium
Sr - strontium

Ti - titanium
V - vanadium
Zn - zinc

BDL - below detection limit.

Elements which were not found above detection limits include:

Sb - antimony, detection limit 8.0 ug/g
As - arsenic, detection limit 15.0 ug/g
Bi - bismuth, detection limit 25.0 ug/g
Se - selenium
Sn - tin, detection limit 1.5 ug/g

b - Sample codes describe the variables used in testing:

1. First position - Stove type: S = Scott Stove, the conventional-technology stove
   B = Earth Stove, the catalytic stove
2. Second position - Fuel type: O = oak
   P = pine
3. Third position - Altitude: L = low altitude or high barometric pressure
   H = high altitude or low barometric pressure
4. Fourth position - Burn rate: L = low, target 1.6 kilograms per hour dry
   H = high, target 3.2 kilograms per hour dry

Test conditions are listed in Table 6. All testing was conducted as described in Section 4 – Experimental Procedures. Run 2 was terminated after 246 minutes due to a lengthy power outage at the test facility. When electrical power was lost, 1.9 kilograms fuel remained in the stove, with flue gas temperatures of about 177°C. The higher emission values observed for Run 2 in comparison to the replicate run (Run 4, SOLH-2) indicate that most emissions occur during the early stages of combustion, and that emissions during the latter stages, especially with a high burn rate, are considerably lower. Run 2 data are presented in most data summaries, but they should be considered atypical of stated test conditions.

Stack gas conditions during testing are listed in Table 7. Stack gas flows were relatively consistent throughout the various tests, averaging about 15 standard cubic meters per hour. Stack gas composition was variable, with concentrations of carbon monoxide (CO) averaging between 1% and 2% for most runs. CO emissions ranged between 179 and 578 grams per hour for the conventional stove, and between 63 and 161 grams per hour for the catalytic stove.

Table 8 lists key operating conditions of the WS^2. Table values are reported in English units, as instrument readings and calculations were all made using this convention. Sample flow rates were typically about 7 liters per minute (0.25 cubic feet per minute), with a dilution ratio of about 15:1. Tests required 2 to 5 filters during the test period.

Test results are compiled in Appendix A.

Particulate Material

Particulate samples are reported in three forms: total particulate capture, the total "grav" fraction and the total TCO fraction (Table 9). Total capture values were substantial, ranging from about 2 to 16 grams of material. The grav-plus-TCO values were expected to be similar to the total capture values because of the high organic content of woodsmoke. However, grav-plus-TCO values were typically 45% to 70% of total capture values. The inorganic material identified by ICAP on the filters accounted for only a few hundred milligrams, which is far less than the several grams difference between total capture and grav-plus-TCO values for the filters. It is not clear why the unextractable fractions from the filter catches were so high. One possible explanation is that inorganics from the ash were entrained in the gas steam from fuel loading and stirring operations, since test burns to which these results are compared were not loaded and stirred during the testing cycle.

Table 10 lists particulate emissions (g/m^3, g/hr and g/kg) as total capture, grav and TCO fractions. Total capture emission rates for the conventional stove ranges from 10.9 grams per hour (pine fuel, low elevation, low burn) to 50.7 grams per hour (pine fuel, high elevation, low burn). While some replicate runs showed close

Table 6. Test Conditions

Run Number	Sample Code[a]	Stove Type[b]	Fuel Type[c]	Barometric Pressure[d] (mb)	Barometric Pressure[d] (in Hg)	Burn Rate[e] (dry kg/hr)	Burn Time[f] (min)	Total Fuel Burned[g] (dry kg)	Fuel Additions[h] (#)	Fuel Moisture[i] (% WB)
1	SOLL-1	Conventional	Oak	1008	29.77	1.35	490	11.0	2	24.8
3	SOLL-2	Conventional	Oak	1011	29.86	1.28	520	11.1	2	24.8
2	SOLH-1	Conventional	Oak	1009	29.81	2.59 [k]	246 [k]	10.6 [k]	2 [k]	24.8
4	SOLH-2	Conventional	Oak	1017	30.04	2.09	500	17.4	4	24.8
6	SPLL-1	Conventional	Pine	1011	29.87	1.66	440	12.3	2	18.5
14	SPLL-2	Conventional	Pine	1004	29.67	1.67	450	12.3	2	20.7
5	SPLH-1	Conventional	Pine	1012	29.89	2.31	430	16.8	3	18.5
16	SPLH-2	Conventional	Pine	1003	29.61	2.92	440	21.1	5	20.7
9	SPHL-1	Conventional	Pine	926 [j]	27.36 [j]	1.18	450	8.9	1	18.5
10	SPHL-2	Conventional	Pine	935	27.62	1.63	430	11.7	2	19.6
7	SPHH-1	Conventional	Pine	929 [j]	27.44 [j]	3.18	430	23.1	5	18.5
8	SPHH-2	Conventional	Pine	926 [j]	27.35 [j]	3.14	420	22.3	5	18.5
12	EPHL-1	Catalytic	Pine	932	27.53	1.33	490	10.7	2	20.7
13	EPHH-1	Catalytic	Pine	930	27.48	1.94	520	16.6	4	20.7

a – Sample codes describe the variables used in testing:

1. First position – Stove type: S = Scott Stove, the conventional-technology stove
E = Earth Stove, the catalytic stove
2. Second position – Fuel type: O = oak
P = pine
3. Third position – Altitude: L = low altitude or high barometric pressure
H = high altitude or low barometric pressure
4. Fourth position – Burn rate: L = low
H = high

b – The conventional stove was a Scott step-top freestanding box stove with a spin-draft air control. The catalytic stove was an Earth Stove Model 1000 C.

c – Oak was eastern red oak from North Carolina. Pine was lodgepole pine from the Boise, Idaho region.

d – Average barometric pressure during testing. Measured with a calibrated barometer at the test site except where noted.

e – Burn rate was calculated on the total dry mass of fuel burned during the sampling period, minus residual ash or charcoal. Burn cycles were "cold-to-cold".

(continued)

Table 6 (continued)

f – Total testing time. Testing started when the fire was lit and continued until less than 5% of total wood mass remained and flue gas temperatures were less than 66°C (150°F). Times listed here include periods when the WS^2 was turned off for filter changes.

g – Total fuel burned, including kindling, normalized to 0 percent moisture.

h – Fuel additions are the number of refuelings after the standard starting procedure. The starting procedure includes a fuel addition at 10 minutes after the start of the test.

i – Fuel moisture was determined by oven drying sample wood blocks. Note that fuel moisture is reported on a wet basis (W-D/W).

j – Values are altitude-corrected from two adjacent airport weather stations.

k – Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned) and a flue gas temperature of about 177°C.

Table 7. Stack Gas Parameters

Run Number	Sample Code[a]	Flue Gas Flow (dscmh)[b]	Average Flue Gas Temperature (°C)	Average CO (%)	Average CO_2 (%)	Average O_2 (%)	CO Emission Rate (g/hr)	CO Emission Factor (g/kg)
1	SOLL-1	15.368	142	0.93	6.5	13.9	178.5	132.2
3	SOLL-2	14.042	118	1.16	6.6	13.4	203.5	159.0
2	SOLH-1	18.872[c]	211[c]	1.55[c]	10.8[c]	9.6	365.4[c]	141.1[c]
4	SOLH-2	17.248	158	1.25	9.5	11.0	269.3	128.9
6	SPLL-1	11.589	171	1.74	12.0	8.0	251.9	151.7
14	SPLL-2	10.642	119	1.78	13.4	7.9	236.6	141.7
5	SPLH-1	14.535	128	1.99	13.4	6.8	361.3	156.4
16	SPLH-2	20.252	195	1.64	12.2	7.3	414.9	142.1
9	SPHL-1	11.077	90	1.88	8.0	11.8	260.2	220.5
10	SPHL-2	12.018	119	1.64	11.3	8.7	246.2	151.0
7	SPHH-1	18.986	204	2.19	14.1	6.2	519.4	163.3
8	SPHH-2	18.652	195	2.48	13.9	6.5	577.9	184.0
12	EPHL-1	10.305	103	0.49	12.2	8.0	63.1	47.4
13	EPHH-2	13.384	129	0.96	13.4	7.3	160.5	82.7

a – Sample codes describe the variables used in testing:

1. First position – Stove type:
   - S = Scott Stove, the conventional-technology stove
   - E = Earth Stove, the catalytic stove
2. Second position – Fuel type:
   - O = oak
   - P = pine
3. Third position – Altitude:
   - L = low altitude, or high barometric pressure
   - H = high altitude, or low barometric pressure
4. Fourth position – Burn rate:
   - L = low, target 1.6 kilograms per hour dry
   - H = high, target 3.2 kilograms per hour dry

b – Dry standard cubic meters per hour. Flue gas flow rate was calculated using Equation 5H-8, EPA Reference Method 5H (Ref. 5)

c – Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned) and a flue gas temperature of about 177°C.

Table 8. WS^2 Operation Conditions

Test Number	Sample Code[a]	QSS[b] (scfm)	QDS[c] (scfm)	QES[d] (sdfm)	Dilution Ratio[e]	Average Sample Gas Temperature[f] (°F)	Average Dilution Chamber Pressure[g] (in. H_2O)	Number of Filters Used[h]
1 3	SOLL–1 SOLL–2	0.247 0.243	3.831 3.742	3.798 3.929	15.383 16.166	183 183	−10.7 −2.2	3 4
2 4	SOLH–1 SOLH–1	0.242 0.247	3.862 3.650	3.951 3.930	16.336 15.938	186 182	−4.1 −2.6	2 2
6 14	SPLL–1 SPLL–2	0.253 0.246	5.249 1.076	3.914 3.966	15.456 16.117	334 266	−3.8 −2.9	2 5
5 16	SPLH–1 SPLH–2	0.263 0.247	3.962 4.359	3.911 3.988	14.859 16.161	110 260	−4.8 −3.3	4 3
9 10	SPHL–1 SPHL–2	0.238 0.249	3.649 4.231	3.721 3.977	15.624 15.940	256 258	−2.1 −2.1	5 3
7 8	SPHH–1 SPHH–2	0.246 0.243	3.910 3.792	3.763 3.743	15.277 15.409	262 260	−2.1 −2.1	3 2
12 13	EPHL–1 EPHH–1	0.255 0.249	4.108 4.113	3.972 3.977	15.577 15.947	253 256	−2.1 −2.1	2 3

a – Sample codes describe the variables used in testing:

1. First position – Stove type: S = Scott Stove, the conventional-technology stove
   E = Earth Stove, the catalytic stove
2. Second position – Fuel type: O = oak
   P = pine
3. Third position – Altitude: L = low altitude or high barometric pressure
   H = high altitude or low barometric pressure
4. Fourth position – Burn rate: L = low
   H = high

b – QSS – flow of sample gas into WS^2 through probe nozzle, ft^3/minute, standard temperature and pressure.

c – QDS – flow of dilution air into WS^2, ft^3/minute, standard temperature and pressure.

d – QES – flow of total (sample plus dilution) air through WS^2, ft^3/minute, standard temperature and pressure.

e – Ratio of dilution air to sample gas flow. This value, with QSS, QDS and QES were calculated using a computer program provided with the WS^2. All instrument readouts and data reduction algorithms were in English units.

f – Flue gas temperature at the inlet to the sample nozzle (top of stack).

g – Average dilution chamber pressure during testing period in inches of water column.

h – Total number of filters used during testing period. A filter change was performed when exhaust inlet vacuum was greater than −50 inches water column.

Table 9. Particulate Sample Lab Values

Run No.	Sample Code[a]	Filter/ Capture (g)[b]	Filter/ Grav (g)[c]	Filter/ TCO(mg)[d]	Probe Rinse/ Grav(g)[e]	Probe Rinse/ TCO(mg)[f]	XAD-2 Grav (g)[g]	XAD-2 TCO(mg)[h]	Total/ Capture (g)[i]	Total/ Grav (g)[j]	Total/ TCO (mg)[k]
1	SOLL-1	4.499	2.6382	116.085	0.3000	2.604	1.1016	898.213	6.805	4.0398	1016.0
3	SOLL-2	5.716	3.8378	5.931	0.1758	1.642	1.6065	727.346	8.229	5.6201	734.0
2	SOLH-1	2.334[l]	1.5193[l]	59.189[l]	0.1617[l]	0.650[l]	0.7385[l]	436.672[l]	3.671[l]	2.4195[l]	495.6[l]
4	SOLH-2	1.052	0.5670	BDL	0.1295	0.510	0.8099	560.971	3.113	1.5064	560.6
6	SPLL-1	1.829	0.8208	19.712	0.2682	4.032	0.2344	563.282	2.899	1.3234	586.1
14	SPLL-2	6.617	4.5705	96.489	0.2984[m]	BDL	0.5967	2137.82	9.650[m]	5.4656[m]	2233.4
5	SPLH-1	1.466	1.0237	11.380	n	BDL	0.2267	997.776	n	n	1009.2
16	SPLH-2	2.107	1.4648	108.991	0.0989[m]	BDL	0.2128	881.597	3.301[m]	1.7765[m]	990.6
9	SPHL-1	12.165	8.3883	510.455	0.3300	BDL	1.4607	2414.640	16.371	10.1790	2922.4
10	SPHL-2	1.560	1.0979	135.300	0.1468	7.674	0.2200	729.650	2.664	1.4647	869.9
7	SPHH-1	1.120	0.6799	23.157	0.1400	3.684	0.1344	501.256	1.899	0.9543	525.4
8	SPHH-2	0.872	0.6869	22.139	0.1387	2.939	0.1657	536.277	1.715	0.9913	558.7
12	EPHL-1	1.342	0.9045	10.973	0.0623	BDL	0.2921	503.148	2.199	1.2589	511.4
13	EPHH-1	0.619	0.3823	BDL	0.0703	BDL	0.1318	1294.070	2.115	0.5844	1291.4
FB[o]	—	0.010	BDL[q]	BDL	BDL	BDL	BDL	0.935	—	BDL	—
HFB[p]	—	0.013	BDL	BDL	BDL	BDL	BDL	2.725	—	BDL	—

a – Sample codes describe the variables used in testing:

1. First position – Stove type: S = Scott Stove, the conventional-technology stove
   E = Earth Stove, the catalytic stove
2. Second position – Fuel type: O = oak
   P = pine
3. Third position – Altitude: L = low altitude or high barometric pressure
   H = high altitude or low barometric pressure
4. Fourth position – Burn rate: L = low
   H = high

b – Net weight of total filter catch. Field blank values have been subtracted.

c – Net weight of gravimetric extract portion of filter catch.

(continued)

Table 9 (continued)

d – Net weight of total chromatographable organics portion of filter catch.
e – Net weight of gravimetric extract portion of probe rinse. Probe rinse consists of material deposited inside the WS^2 from the probe tip to the filter.
f – Net weight of total chromatographable organics portion of probe rinse.
g – Net weight of gravimetric extract portion of XAD-2 resin catch.
h – Net weight of total chromatographable organics portion of XAD-2 resin catch.
i – Sum of filter capture, probe rinse gravimetric, XAD-2 gravimetric, probe rinse TCO and XAD-2 TCO values.
j – Sum of filter gravimetric, probe rinse gravimetric and XAD-2 gravimetric values.
k – Sum of filter TCO, probe rinse TCO and XAD-2 TCO values.
l – Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned).
m – Lab weights for probe rinses did not stabilize within data QA limits. Data were used due to small relative impact of weighing discrepancy on total mass.
n – Gravimetric probe rinse portion of Run 5 was lost during laboratory handling.
o – Field blank from low elevation site. Subtracted from test values.
p – Field blank from high elevation site. Subtracted from test values.
q – Below detection limit.

Table 10. Particulate Matter Emissions

Run Number	Sample Code[a]	Flue Gas Flow (dscmh)[b]	Sample Volume (l)[c]	Particulate Concentration (g/m³)[d]			Particulate Emission Rate (g/hr)[e]			Particulate Emission Factor (g/kg)[f]		
				Total[g]	Grav.[h]	TCO[i]	Total[g]	Grav.[h]	TCO[i]	Total[g]	Grav.[h]	TCO[i]
1	SOLL-1	15.368	3,315.6	2.052	1.218	0.306	31.5	18.7	4.7	23.3	13.9	3.5
3	SOLL-2	14.042	3,330.8	2.471	1.687	0.220	34.7	23.7	3.1	27.1	18.5	2.4
2[j]	SOLH-1	18.872	1,590.0	2.309	1.522	0.312	43.6	28.7	5.9	16.8	11.1	2.3
4	SOLH-2	17.248	3,385.6	0.919	0.445	0.166	15.6	7.7	2.9	7.5	3.7	1.4
6	SPLL-1	11.589	3,080.9	0.941	0.430	0.190	10.9	5.0	2.2	6.6	3.0	1.3
14	SPLL-2	10.642	3,344.0	2.886	1.634	0.668	30.7	17.4	7.1	18.4	10.4	4.3
5	SPLH-1	14.535	2,979.3	k	k	0.339	k	k	4.9	k	k	2.1
16	SPLH-2	20.252	2,965.9	1.113	0.599	0.334	22.5	12.1	6.8	7.7	4.1	2.3
9	SPHL-1	11.077	3,579.0	4.574	2.844	0.817	50.7	31.5	9.0	43.0	26.7	7.6
10	SPHL-2	12.018	2,870.0	0.928	0.510	0.303	11.2	6.1	3.6	6.9	3.7	2.2
7	SPHH-1	18.986	2,800.6	0.678	0.341	0.188	12.9	6.5	3.6	4.1	2.0	1.1
8	SPHH-2	18.652	2,821.5	0.608	0.351	0.198	11.3	6.5	3.7	3.6	2.1	1.2
12	EPHL-1	10.305	3,661.4	0.601	0.344	0.140	6.2	3.5	1.4	4.7	2.6	1.1
13	EPHH-1	13.384	3,518.8	0.601	0.166	0.367	8.0	2.2	4.9	4.1	1.1	2.5

a – Sample codes describe the variables used in testing:

1. First position	– Stove type:	S = Scott Stove, the conventional-technology stove
		E = Earth Stove, the catalytic stove
2. Second position	– Fuel type:	O = oak
		P = pine
3. Third position	– Altitude:	L = low altitude or high barometric pressure
		H = high altitude or low barometric pressure
4. Fourth position	– Burn rate:	L = low
		H = high

b – Dry standard cubic meters per hour. Flue gas flow rate was calculated using Equation 5H-8, EPA Reference Method 5H (Reference 5).

c – Liters. Product of QSS and net sampling time. QSS was calculated from WS² venturi ΔP values.

(continued)

Table 10 (continued)

d – Grams of particulate material per standard cubic meter.
e – Grams of particulate material per hour.
f – Grams of particulate material per dry kilogram fuel burned.
g – Consists of total net weight of filters plus gravimetric and TCO values from probe rinse and XAD-2 resin.
h – Gravimetric particulate catch. Sum of values from filters, probe and XAD-2 residual when processed by "grav" procedures.
i – Total chromatographable organics. Sum of values from filters, probe rinse and XAD-2 residual when processed for TCO.
j – Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned).
k – Gravimetric probe rinse portion of Run 5 lost during laboratory handling.

agreement (Runs 1 and 3, 7 and 8, and 12 and 13), other runs showed considerable differences; Runs 2 and 4, 6 and 14, and 9 and 10 varied by factors of 3 to 4 (Figure 4). Agreement and discrepancies between the replicate runs were similar when reported as grams per kilogram.

While the semivolatile (TCO) fraction was variable as a percentage of the total particulate emission rate, the absolute value (in grams per hour) was more consistent (Figure 4). The condensible (grav) fraction (as grams per hour) appears to be the most variable portion of the total particulate emission rate. The grav fraction showed good correlation with the total capture values (Figure 5). The discrepancies of measured parameters between Runs 2 and 4 are probably attributable to the premature end to Run 2. Figures 6, 7 and 8 show the effect of burn rate on the various particulate fraction emission rates. It appears that a number of factors can and do affect particulate emissions from woodstoves. The cold start procedure used in this testing probably contributed to variability of test results, but represents conditions likely to be encountered in actual stove use. None of the particulate emission parameters of total capture, grav or TCO fractions showed statistically significant effects as a function of test variables at the 95% confidence bound. Figures 9, 10, 11 and 12 show total particulate emission rates compared by fuel type, stove type, altitude and burn rate.

Another factor in variability of results between test runs is the possible plugging of the sample venturi during testing. The venturi was often partially or completely occluded during sample recovery, although it was not always clear when it became plugged. The venturi was cleaned during Run 14 after test personnel noted discrepancies in flow readings. The design of the sampler makes detection of a plugged sample probe difficult, as a pressure differential is always evident across the venturi, even if the venturi is plugged, due to vacuum in the dilution chamber. Partial occlusion of the sample venturi will decrease the flow values calculated from a given pressure differential and thereby result in under-reporting emission values.

Polynuclear Aromatic Hydrocarbons (PAH)

Most of the measured PAH compounds were lower-molecular weight compounds; high molecular weight compounds had lower emission rates (Table 11). Naphthalene accounted for almost half of the emissions of measured PAH compounds in many samples (Runs 4, 6, 14, 16, 10, 7, 8, 12 and 13). A very large fraction of total PAH compounds were recovered from the filter and XAD-2 resin extract fractions, with a relatively small contribution from the probe rinse fraction. This is primarily a function of sample gas temperature; the probe was typically heated to about 80°C, while the filter and XAD-2 resin were maintained at ambient temperature.

Probe rinses from Runs 1 through 8 were not analyzed for PAH compounds. These samples were recovered with a methanol rinse prior to a dichloromethane rinse, causing uncertainty as to whether any reactions of the methanol with PAH compounds had occurred prior to analysis. However, once the error in

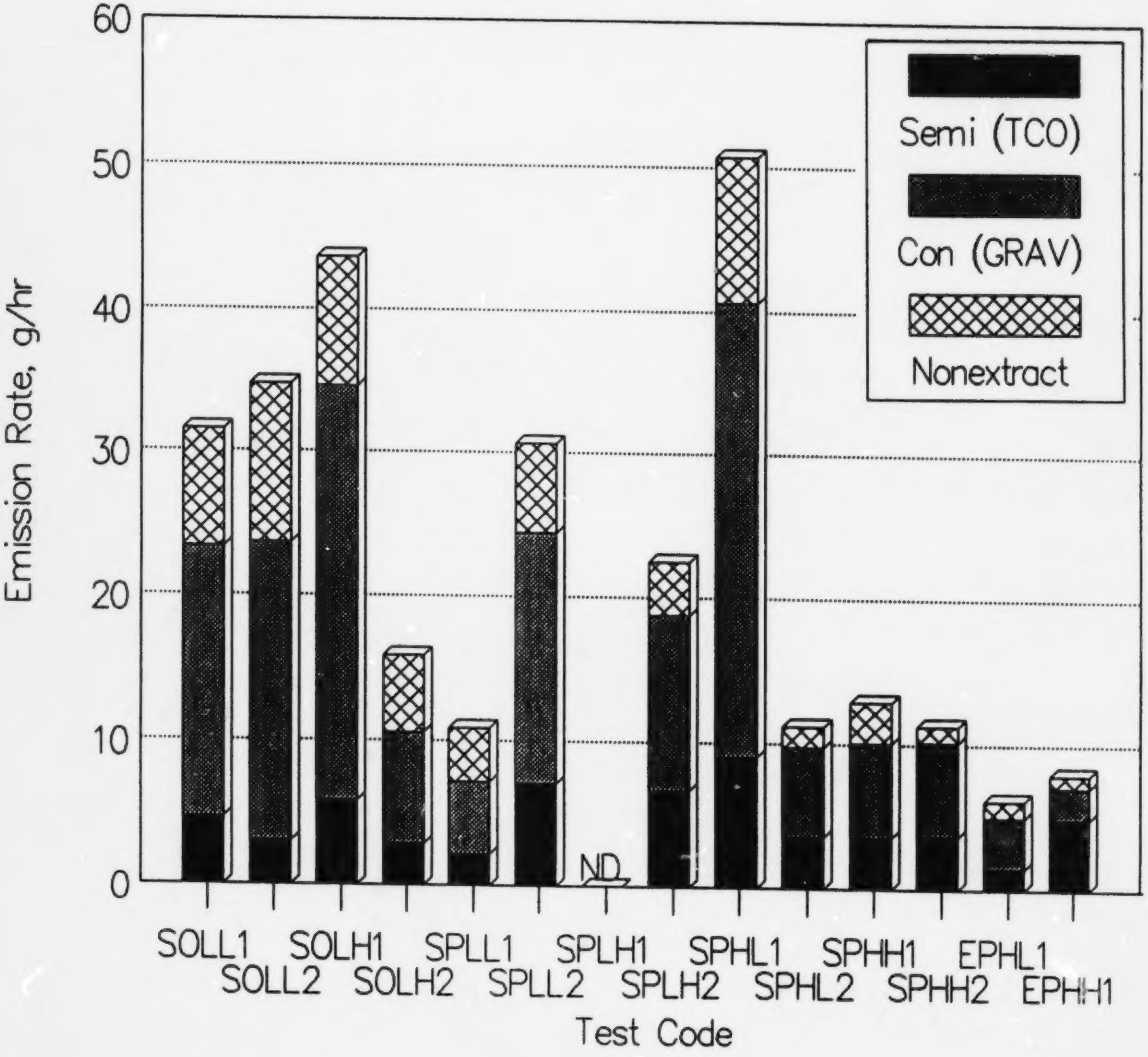

Figure 4. Emission rates for particulate capture fractions.

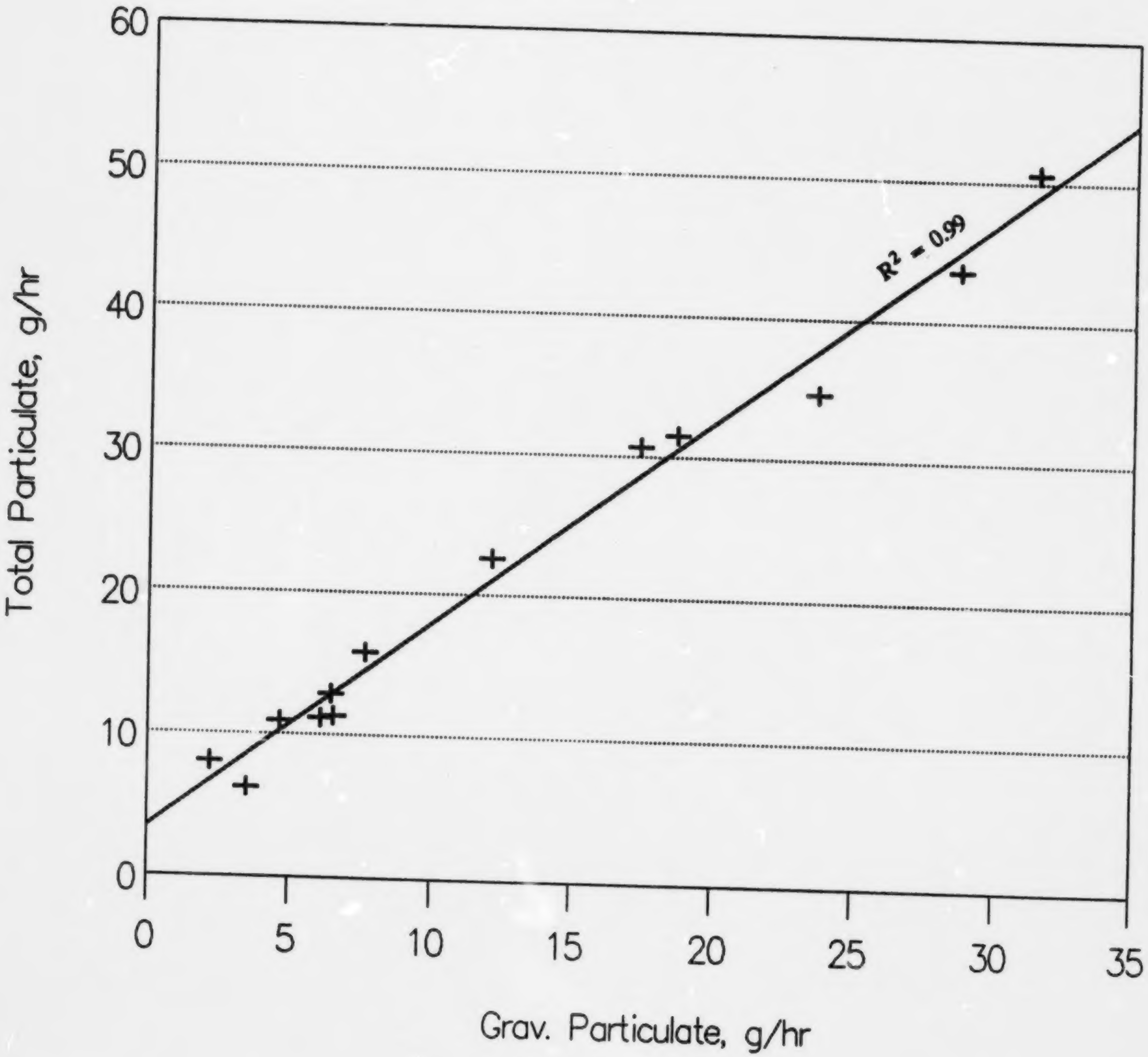

Figure 5. Correlation of gravimetric fraction and total particulate emission rates.

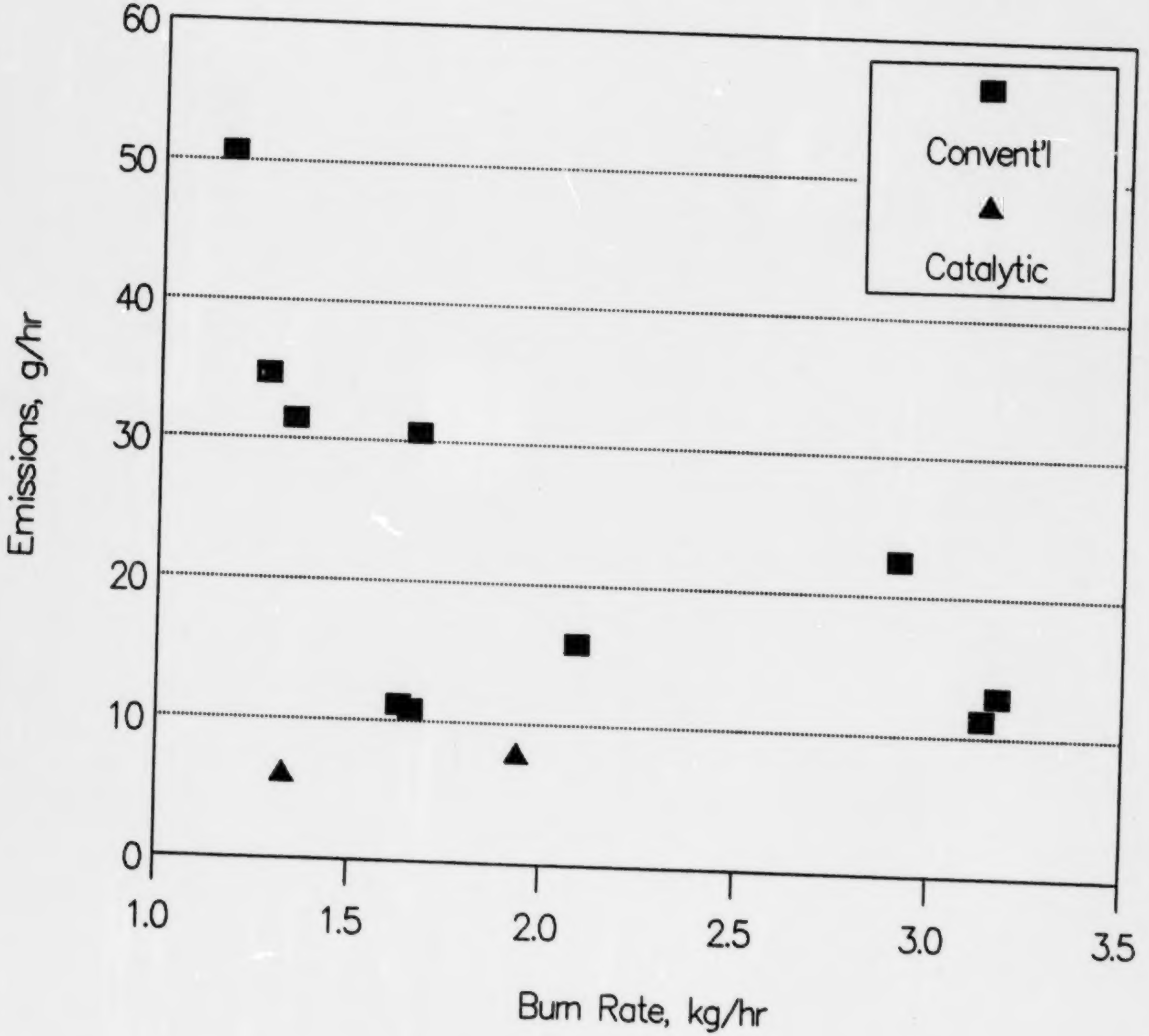

Figure 6. Total capture particulate emissions as a function of burn rate.

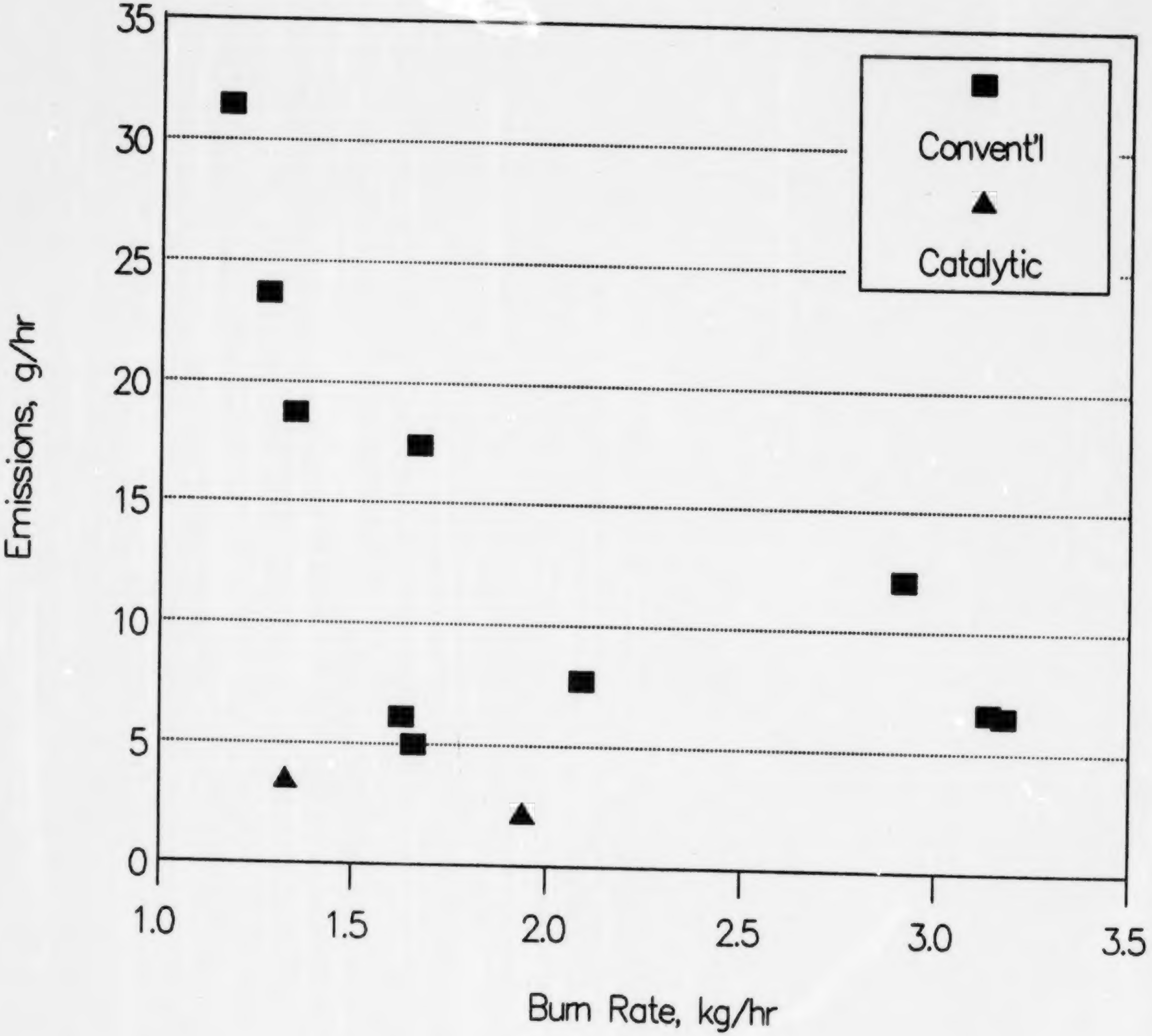

Figure 7. Condensible (gravimetric) particulate emissions as a function of burn rate.

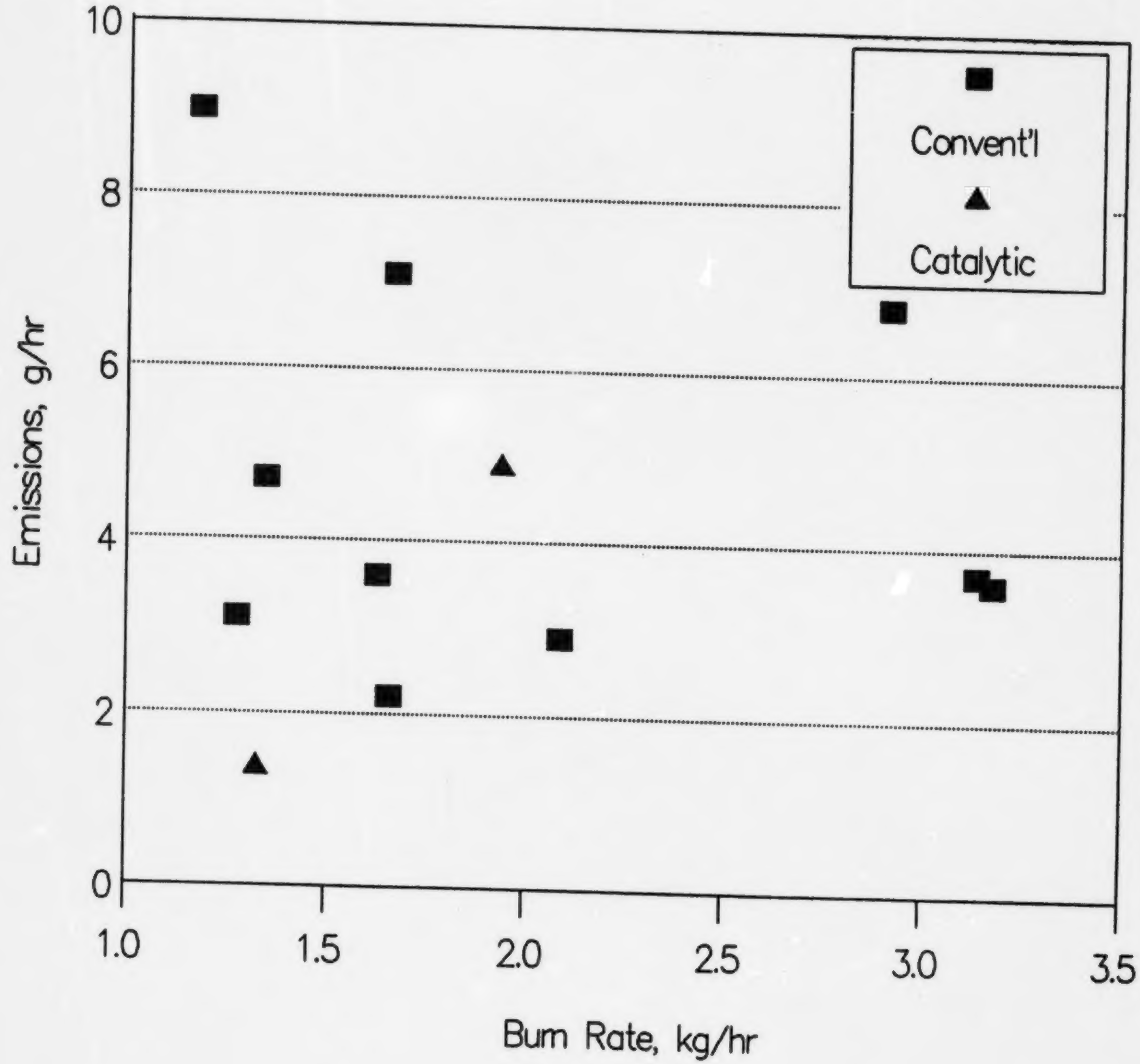

Figure 8. Semivolatile (TCO) particulate emissions as a function of burn rate.

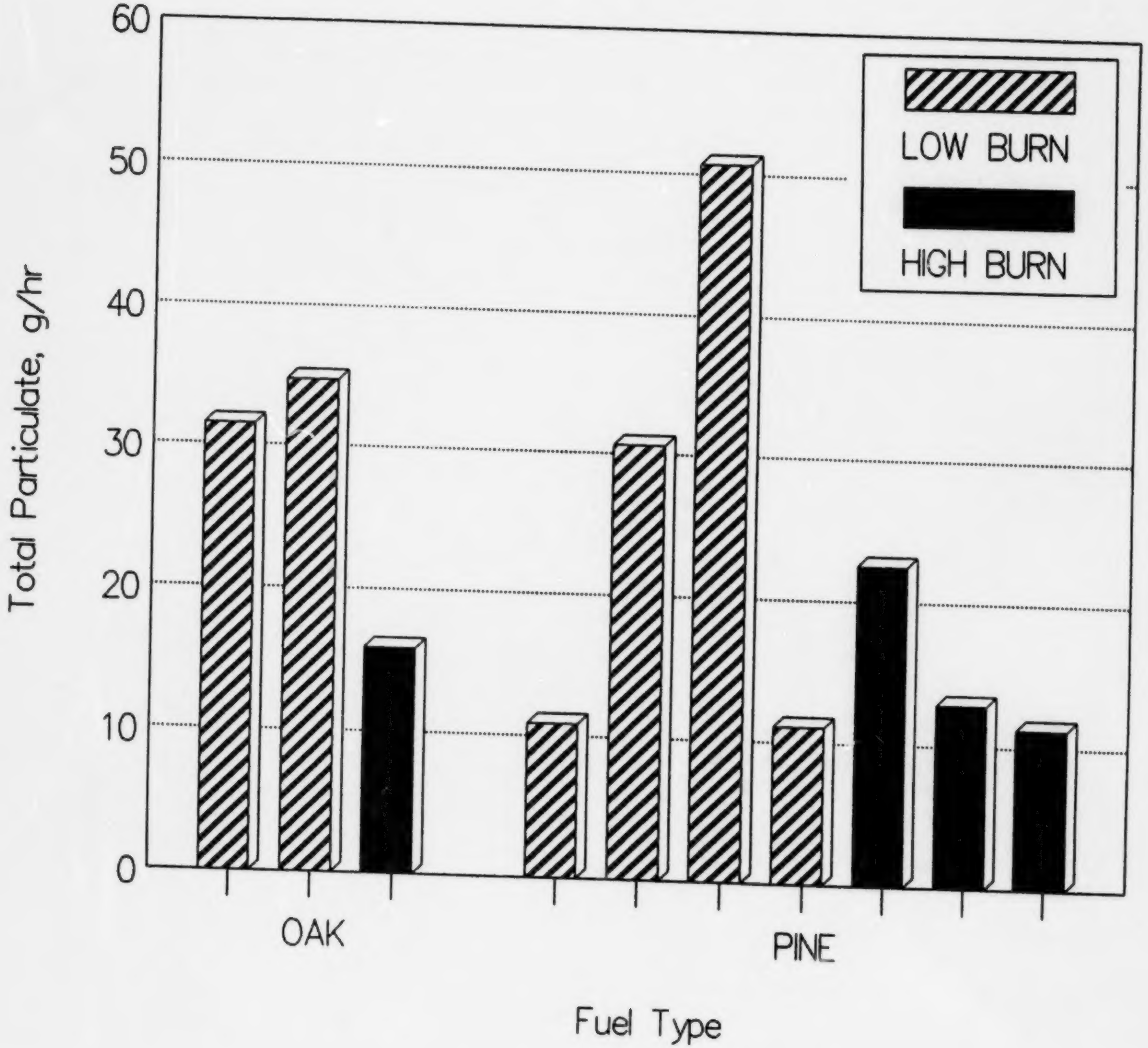

Figure 9. Effect of fuel type on particulate emissions (conventional stove).

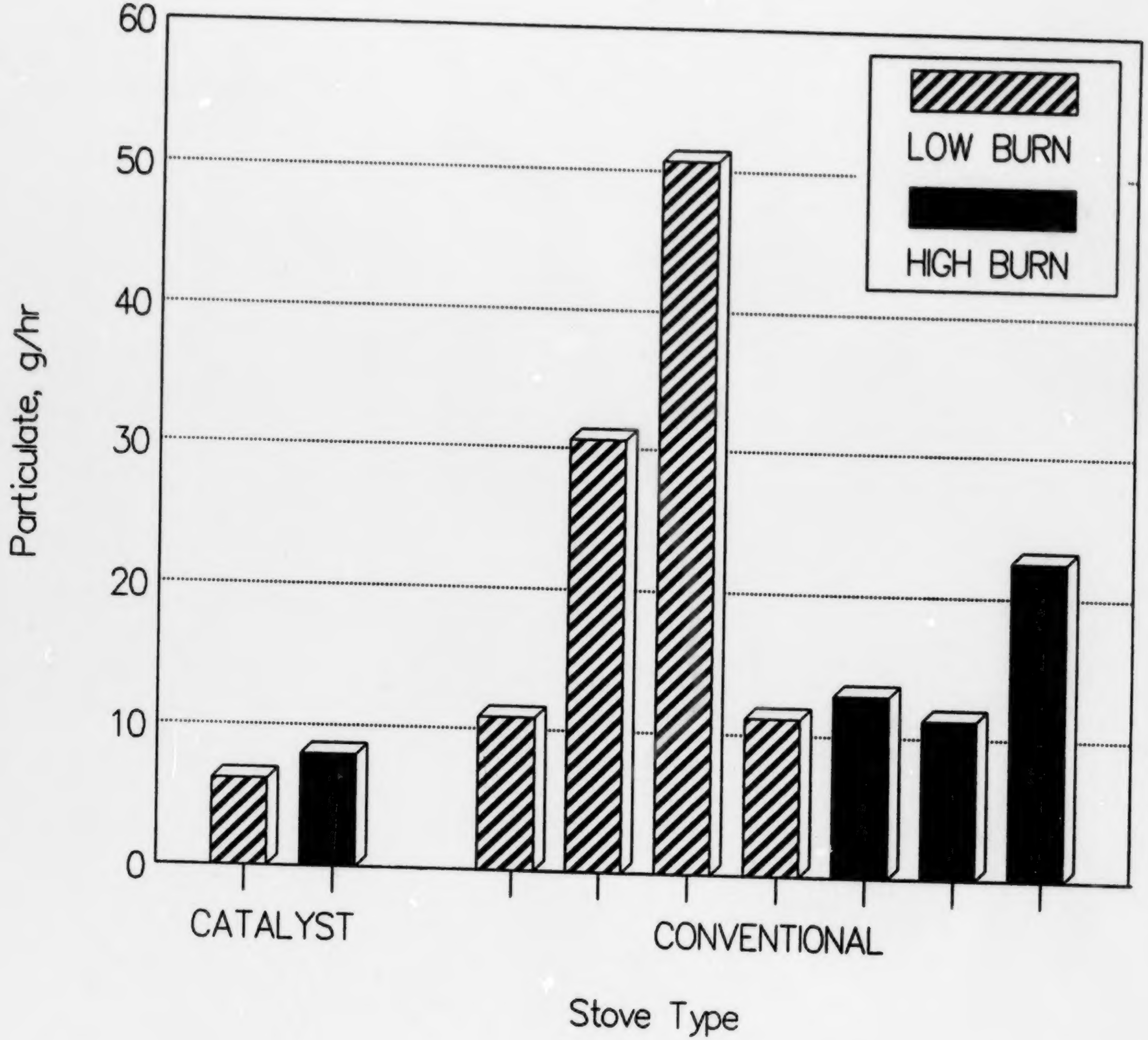

Figure 10. Effect of stove type on particulate emissions (pine fuel).

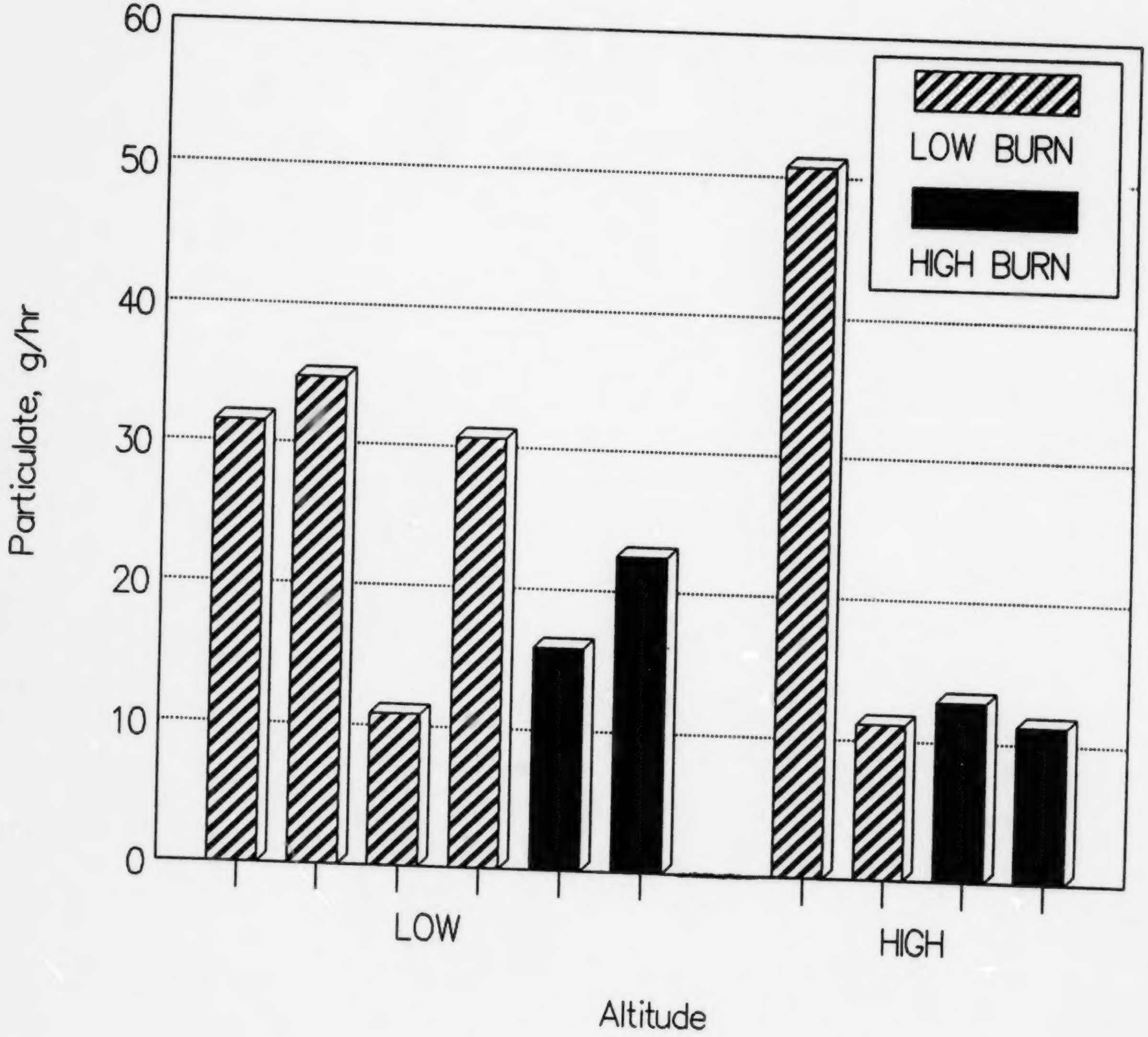

Figure 11. Effect of altitude on particulate emissions (conventional stove).

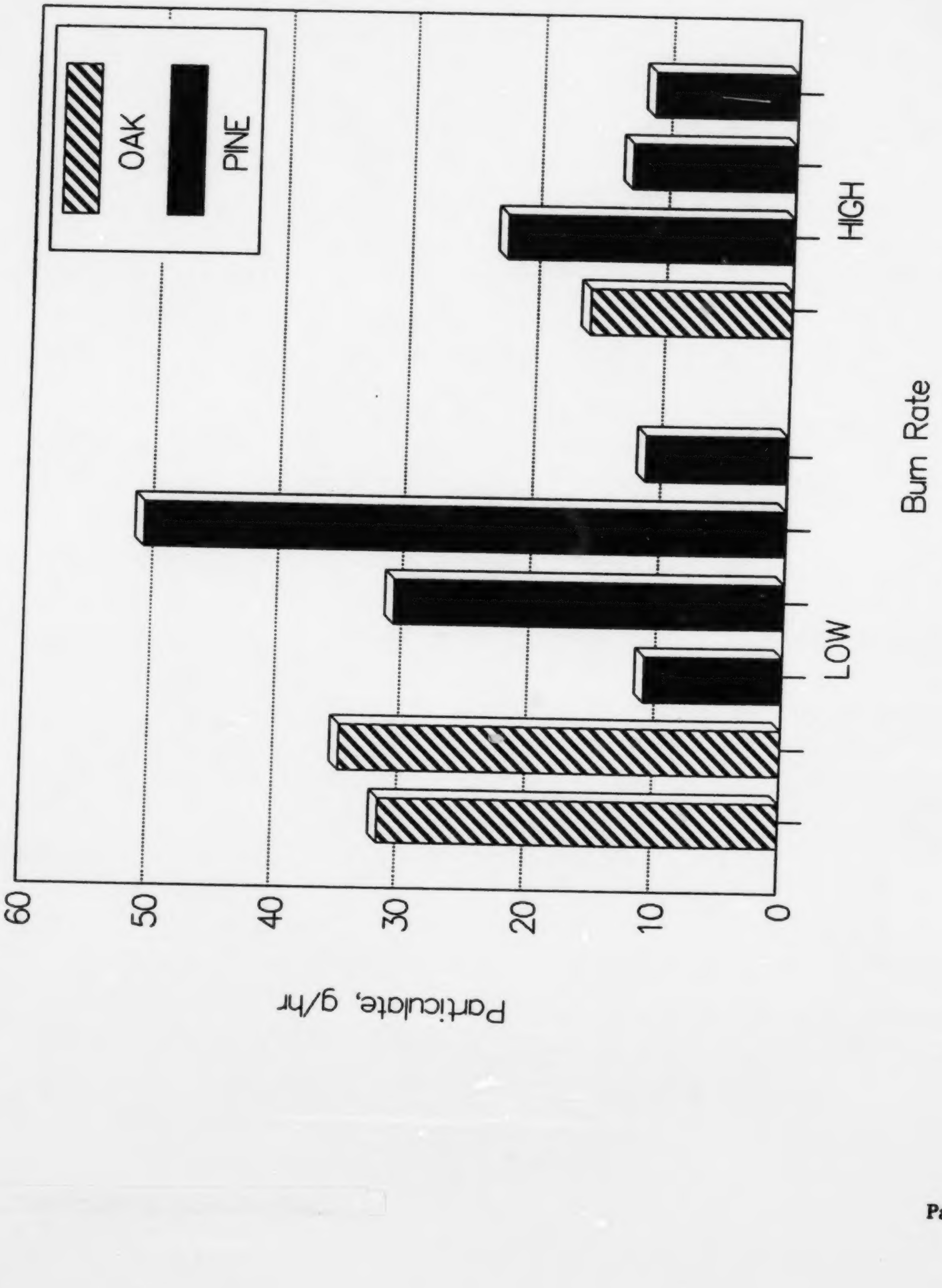

Figure 12. Effect of burn rate on particulate emissions (conventional stove).

Table 11. Polynuclear Aromatic Hydrocarbon (PAH) Emissions

Run Number	1	3	2	4	6	14	5	16	9	10	7	8	12	13
Sample Code^a	SOLL-1^c	SOLL-2^c	SOLH-1^c	SOLH-2^c	SPLL-1^c	SPLL-2	SPLH-1^c	SPLH-2	SPHL-1	SPHL-2	SPHL-1^c	SPHH-2^c	EPHL-1	EPHH-1
Barometric Pressure(mb)	1008	1011	1009	1017	1011	1004	1012	1003	926	935	929	926	932	930
Burn Rate (kg/hr)	1.35	1.28	2.59	2.09	1.66	1.67	2.31	2.92	1.18	1.63	3.18	3.14	1.33	1.94
Compound	Emissions (mg/hr)													
Naphthalene	58	91	297^d	144	189	438	426^e	857	79	320	588	400	131	313
Acenaphthylene	0	153	198^d	69	148	336	356^e	210	281	114	313	332	96	119
Acenaphthene	39	0	0^d	0	0	0	59^e	0	0	0	86	0	0	0
Fluorene	10	16	21^d	13	9	29	20^e	67	20	26	42	27	9	8
Phenanthrene	20	26	67^d	29	30	107	79^e	325	40	123	114	71	32	72
Anthracene	3	4	8^d	4	5	14	13^e	51	8	19	16	38	4	10
Fluoranthene	5	5	21^d	10	8	24	22^e	91	8	34	28	22	8	17
Pyrene	5	6	28^d	9	11	26	25^e	113	14	33	23	17	7	18
Benzo(a)anthracene	2	7	14^d	3	14	36	17^e	82	5	38	32	7	13	27
Chrysene	0	0	1^d	0	7	67	11^e	17	2	19	11	2	9	12
Benzo(e)pyrene	0	1	5^d	2	4	23	9^e	32	21	15	12	8	6	1
Benzo(b)fluoranthene	0	1	4^d	1	2	10	5^e	20	15	7	6	4	1	4
Benzo(k)fluoranthene	0	0	2^d	0	1	1	2^e	7	1	3	2	1	0	1
Benzo(a)pyrene	1	1	5^d	1	2	4	4^e	17	2	8	4	3	1	3
Benzo(g,h,i)perylene	0	1	3^d	2	1	9	1^e	19	0	4	5	3	2	2
Dibenzo(a,h)anthracene	0	0	1^d	0	0	0	4^e	5	0	1	1	1	1	0
Indeno(1,2,3cd)pyrene	0	0	0^d	0	0	0	0^e	0	0	0	0	0	0	0
Total GC/MS PAH^b	144	316	682^d	291	440	1150	1221^e	1908	494	761	1311	956	291	605

(continued)

Table 11 (continued)

a – Sample codes describe the variables used in testing:

1. First position – Stove type:
   - S =Scott Stove, the conventional-technology stove
   - B =Earth Stove, the catalytic stove
2. Second position – Fuel type:
   - O =oak
   - P =pine
3. Third position – Altitude:
   - L =low altitude or high barometric pressure
   - H =high altitude or low altitude barometric pressure
4. Fourth position – Burn rate:
   - L =low
   - H =high

b – Sum of identified PAH compounds.

c – Runs 1 through 8 did not have the probe rinse fraction analyzed for PAH. The probe rinse fraction averaged 2.5% of the total PAH mass for tests on the Scott Stove (range 1.3% to 4.0%); total PAH values were factored up by 2.5%, then corrected by the total field blank value. Individual compounds were not corrected for field blanks.

d – Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned).

e – Gravimetric probe rinse portion of Run 5 lost during laboratory handling.

the analytical procedures was discovered, it was corrected and Samples 9, 10, 11, 14, and 16 received the dichloromethane rinse first. The probe rinse fraction, which accounted for an average of only 2.5% of total PAH compounds in Runs 9, 10, 11, 14 and 16, was factored into the total PAH values for Runs 1 through 8 shown in Table 11. Therefore, Runs 1 through 8 have been factored up by 2.5% to represent probable values (±2%). Values for individual PAHs were not adjusted.

Emission rates of total measured PAH compounds ranged from 144 mg/hr from Run 1 (conventional stove, oak fuel, low elevation, low burn) to 1,908 mg/hr from Run 16 (conventional stove, pine fuel, low elevation, high burn).

Emissions of PAH compounds were quite variable between replicate runs and between test conditions. Figures 13 and 14 illustrate the effect of burn rate on the emission rate of total measured PAHs and selected PAH compounds.

Volatile Organic Compounds (VOC)

Table 12 presents volatile organic compound emission rates. Total VOC emissions (C_1 - C_7 hydrocarbons) ranged from 9 gm/hr (Run 6) to 41 gm/hr (Run 9). Replicates for Runs 5 and 16 and Runs 7 and 8 were in relatively close agreement, as were both runs with the catalytic stove (Runs 12 and 13). Other replicate tests showed considerable variation. Methane composed the largest single fraction of most samples, although Run 1 had no reported methane. Ethylene emission rates were second highest for most samples. Figure 15 shows the effect of burn rate on methane, benzene and total $C_1 - C_7$ hydrocarbons.

The VOC emissions from both the conventional and the catalytic stoves were consistent with results from other projects which showed VOC emission rates to be about the same order of magnitude higher when samples were collected directly from the stack.[1,3]

Inorganic Emissions

The inorganic composition of WS^2 filters was measured by inductively coupled argon plasma (ICAP) spectrograph after solvent extraction. Based on filter catches, inorganic emission rates were highest for sodium (Na) and potassium (K), ranging from 0 to 56 mg/hr and 4 to 78 mg/hr, respectively. Calcium (Ca) and barium (Ba) were also relatively high, averaging between 0 and 18 mg/hr. Emission rates were variable among runs for all measured elements (Table 13).

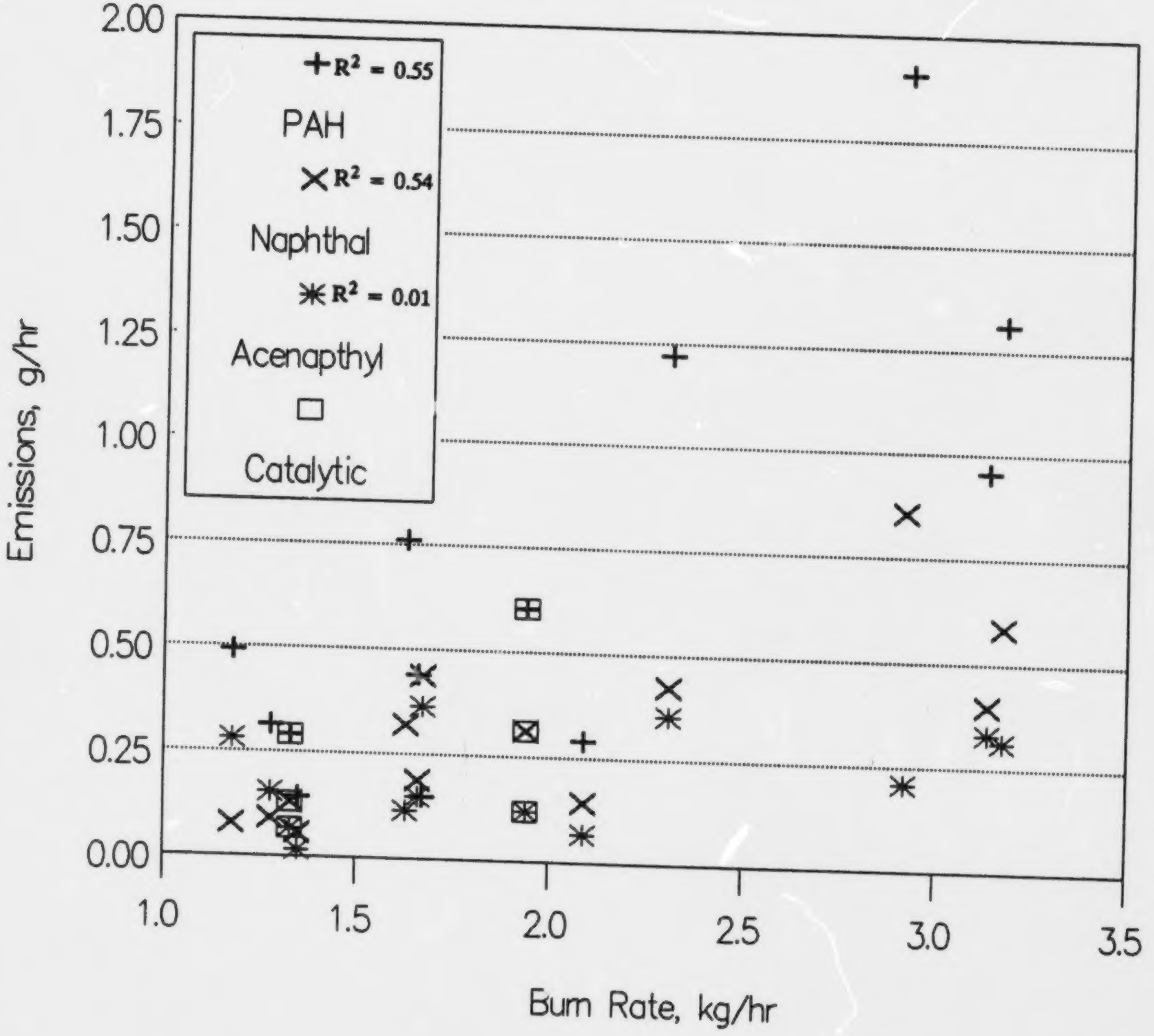

Figure 13. PAH, naphthalene, and acenaphthylene emissions as a function of burn rate. Rectangles indicate data from catalytic stove.

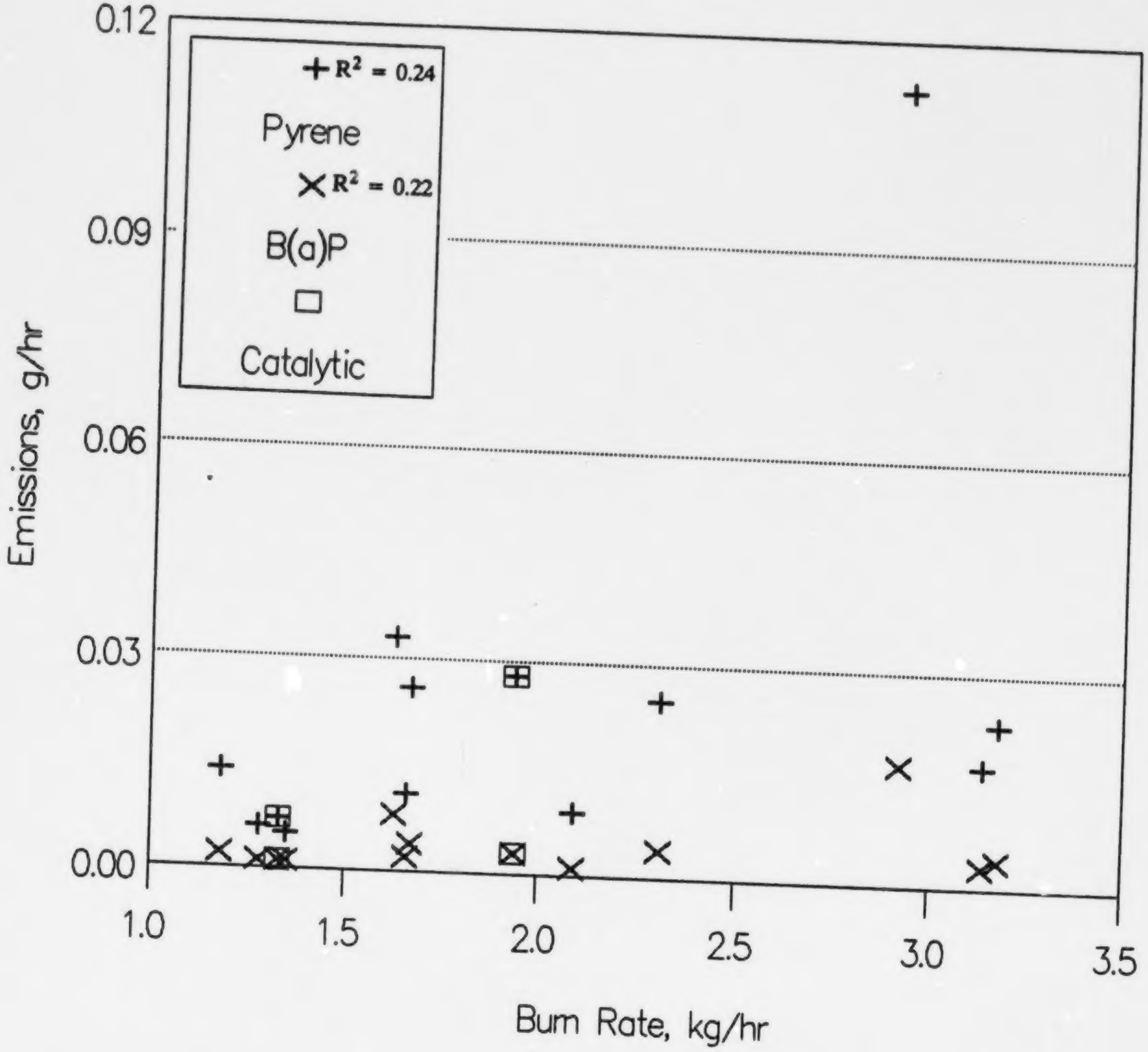

Figure 14. Pyrene and benzo(a)pyrene emissions as a function of burn rate. Rectangles indicate data from catalytic stove.

Table 12. Volatile Organic Compound Emissions

Test Number	1	3	2	4	6	14	5	16	9	10	7	8	12	13
Sample Code[a]	SOLL-1	SOLL-2	SOLH-1	SOLH-2	SPLL-1	SPLL-2	SPLH-1	SPLH-2	SPHL-1	SPHL-2	SPHH-1	SPHH-2	EPHL-1	EPHH-1
Barometric Pressure	1008	1011	1009	1017	1011	1004	1012	1003	926	935	929	926	932	930
Burn Rate	1.35	1.28	2.59 [e]	2.09	1.66	1.67	2.31	2.92	1.18	1.63	3.18	3.14	1.33	1.94
Compound	Emissions (mg/hr)													
Methane	0	5491	5821 [e]	2883	3581	11581	3823	6265	19401	4785	10135	3026	10113	7528
Ethane	1154	1623	1734 [e]	594	254	2021	933	1175	3129	600	946	806	1370	670
Ethylene	2888	3759	6314 [e]	3836	1333	5612	5167	6142	4811	3918	3118	5091	2066	3740
Acetylene	632	699	1583 [e]	831	299	1243	1245	2295	717	1151	2062	1593	367	559
Propane	271	424	362 [e]	102	57	524	179	145	948	108	144	124	134	110
Propene	844	1136	1425 [e]	508	286	1798	1164	1453	2105	857	1053	843	499	696
i-Butane	26	29	30 [e]	11	4	33	14	12	73	7	12	11	7	8
n-Butane	51	70	59 [e]	14	9	62	63	17	145	13	18	15	12	10
Butenes[b]	875	1208	1609 [e]	0	522	1576	1260	1594	1838	807	957	724	559	569
Pentenes[c]	698	977	1011 [e]	0	143	560	281	260	1156	280	413	345	110	130
C_6 Hydrocarbons[d]	281	786	598 [e]	0	129	714	336	433	622	193	255	190	129	103
Benzene	832	1265	2262 [e]	0	1117	2697	2968	4209	1537	1908	3024	2232	952	1450
Toluene	280	477	554 [e]	0	329	1244	914	1521	1051	649	768	607	351	495
Furan	192	288	431 [e]	0	190	439	489	689	307	299	424	352	86	114
Methyl Ethyl Ketone	246	429	415 [e]	0	60	408	176	150	638	71	112	91	53	43
2-Methyl Furan	834	1377	1095 [e]	0	113	560	206	173	1349	85	124	103	68	64
2,5-Dimethyl Furan	205	355	252 [e]	0	22	153	49	53	325	23	30	23	17	16
Furfural	521	1110	663 [e]	0	85	671	164	394	676	150	112	135	135	85
O-Xylene	66	111	173 [e]	0	99	433	283	648	218	268	0	0	128	176
Total NMHC	10896	16124	20570 [e]	5895	5051	20749	15891	21364	21646	11388	13572	13286	7043	9037
Total HC	10896	21615	26390 [e]	8779	8632	32330	19714	27629	41047	16173	23707	21313	17156	16565

(continued)

Table 12 (continued)

a - Sample codes describe the variables used in testing:

1. First position - Stove type: S = Scott Stove, the conventional-technology stove
   E = Earth Stove, the catalytic stove
2. Second position - Fuel type: O = oak
   P = pine
3. Third position - Altitude: L = low altitude
   H = high altitude
4. Fourth position - Burn rate: L = low
   H = high

b - 1-butene, i-butene, t-2-butene, c-2-butene, 2-me-1-butene and 2-me-butene are reported as butenes.

c - 1-pentene, t-2-pentene and c-2-pentene are reported as pentenes.

d - C_6 hydrocarbons include 2,2-dimethylbutane; 2,3-dimethylbutane; 2-methyl-pentane; 3-methyl-pentane; n-hexane; t-2-hexane; c-2-hexene; methylcyclopentane; and cyclohexane as one group. Values reported as hexane equivalents (MW = 86.18).

e - Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned).

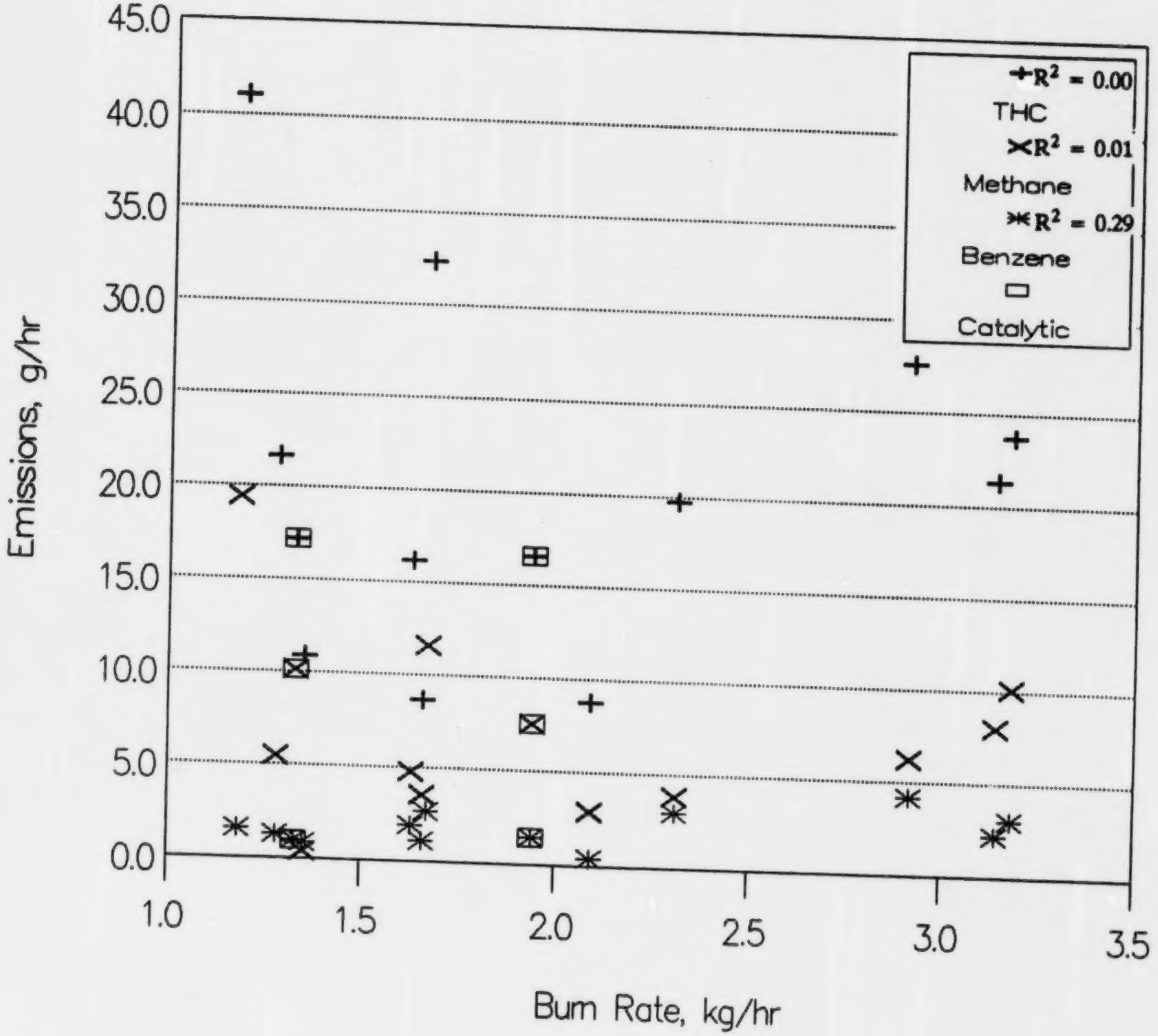

Figure 15. C_1 through C_7 hydrocarbon emissions as a function of burn rate. Rectangles indicate data from catalytic stove.

Table 13. Elemental Emissions[a]

Run Number	1	3	2[c]	4	6	14	5	16	9	10	7	8	12	13
Fuel Type	Oak	Oak	Oak	Oak	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine
Sample Code	SOLL-1	SOLL-2	SOLH-1	SOLH-2	SPLL-1	SPLL-2	SPLH-1	SPLH-2	SPHL-1	SPHL-2	SPHH-1	SPHH-2	EPHL-1	EPHH-1
Compound	Emissions (mg/hr)[b]													
Aluminum (Al)	0.918	8.142	8.681	1.862	0.416	2.583	2.951	1.009	8.759	0.539	10.492	25.946	0.000	1.137
Barium (Ba)	0.867	12.260	10.694	2.216	0.000	7.985	3.524	6.339	13.525	0.392	18.479	7.961	0.000	3.157
Cadmium (Cd)	0.000	0.047	0.000	0.000	0.000	0.039	0.082	0.000	0.000	0.049	0.000	0.000	0.060	0.000
Calcium (Ca)	2.039	11.512	11.952	6.205	0.416	4.815	2.951	2.449	14.351	0.588	16.286	7.076	2.530	2.399
Chromium (Cr)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cobalt (Co)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Copper (Cu)	0.051	0.374	0.252	0.089	0.000	0.157	0.164	0.000	0.358	0.000	0.470	0.000	0.000	0.000
Iron (Fe)	0.204	1.263	1.007	0.266	0.000	0.352	0.410	0.144	0.881	0.000	0.783	0.147	0.060	0.189
Lead (Pb)	0.051	0.094	0.126	0.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.151	0.063
Magnesium (Mg)	0.255	2.714	2.516	0.621	0.093	0.626	0.902	0.288	3.498	0.000	4.072	1.622	0.090	0.000
Manganese (Mn)	0.102	0.187	0.252	0.266	0.000	0.117	0.082	0.144	0.275	0.049	0.157	0.147	0.211	0.126
Nickel (Ni)	0.000	0.000	0.000	0.000	0.000	0.039	0.000	0.144	0.000	0.000	0.000	0.000	0.000	0.000
Phosphorus (PO_4)	0.306	0.515	1.007	0.443	0.000	0.196	0.246	0.000	0.634	0.196	0.470	0.295	0.452	0.253
Potassium (K)	36.659	49.650	78.382	48.311	3.655	16.166	17.458	14.696	22.367	5.291	31.633	17.690	3.523	7.640
Silver (Ag)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sodium (Na)	8.770	56.295	54.477	9.219	1.573	29.945	28.113	13.399	53.714	4.066	0.000	43.488	0.000	5.619
Strontium (Sr)	0.051	0.187	0.126	0.089	0.000	0.157	0.082	0.000	0.193	0.000	0.157	0.147	0.030	0.126
Tin (Sn)	0.102	0.374	0.000	0.000	0.000	0.000	0.328	0.000	0.220	0.000	0.157	0.000	0.000	0.000
Titanium (Ti)	0.000	0.094	0.000	0.000	0.000	0.000	0.082	0.000	0.083	0.000	0.157	0.000	0.000	0.000
Vanadium (V)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zinc (Zn)	0.459	8.798	7.423	1.507	0.278	7.790	2.787	3.602	89.743	0.686	14.564	6.044	0.000	4.104

(continued)

Table 13 (continued)

a – Samples were analyzed by inductively-coupled argon plasma (ICAP) spectroscopy at a commercial laboratory. All results are reported as micrograms per gram (parts per million mass) of dry sample.

Al - aluminum
Ba - barium
Be - beryllium
B - boron
Cd - cadmium
Ca - calcium
Cr - chromium
Co - cobalt
Cu - copper
Fe - iron
Pb - lead
Mg - magnesium
Mn - manganese
Mo - molybdenum
Ni - nickel
PO_4 - phosphorus
K - potassium
SiO_2 - silicon
Ag - silver
Na - sodium
Sr - strontium
Sn - tin
Ti - titanium
V - vanadium
Zn - zinc

b – Filter values were reported as micrograms per square centimeter (ug/cm^2). Values reported here were calculated as follows:

$$\frac{\text{ug}}{\text{run}} = \left[\frac{\text{ug}}{\text{cm}^2} - \frac{\text{ug}}{\text{cm}^2\,\text{blank}}\right]\left[\left[\frac{\text{total cm}^2}{\text{filter}} \times \frac{\text{total no. filters}}{\text{run}}\right] - \left[\frac{\text{cm}^2\text{ border}}{\text{filter}} \times \frac{\text{total no. filters}}{\text{run}}\right]\right]$$

$$\frac{\text{mg}}{\text{hr}} = \frac{\text{ug}}{\text{run}} \times \frac{\text{mg}}{1000\text{ ug}} \times \frac{\text{run}}{\text{m}^3\text{ sample}} \times \frac{\text{m}^3\text{ stack flow}}{\text{hr}}$$

c – Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned).

Aldehydes

Results from aldehyde testing did not meet quality assurance objectives and are therefore not presented in this report. Sampling was conducted using dual cartridges, with one operating at a flow rate twice as high as the other. Poor correlation between the cartridges indicated sample breakthrough.

Statistical Analysis

Calibration Procedures

WSDSS - During initial startup the power was switched on and the transducer box was plugged in and allowed to warm up for 45 minutes; then the transducer was zeroed with the pressure taps open to atmosphere. Span check was done by connecting the high side of each transducer in parallel with a manometer, blowing lightly into the manometer and adjusting to match the manometer.

Then the braided line was temporarily disconnected from the dilution air blower and plugged into the connection on the sampler (with a Swagelock™ cap), and a surgical tubing jumper was placed between the orifice taps. The dilution blower switch was turned on. Speed changes in response to changes in the variac settings on the control module were noted. Next, the sample inlet on the inlet module was plugged with a cap and the exhaust pump was turned on. The coarse and fine flow valves for an exhaust inlet pressure (top Magnehelic gauge) were adjusted to about 100 inches WG and the "ΔP" sample readout was checked to see if it read zero. Then the dilution blower was reconnected to the sampler and the transducer lines to the orifice taps. The probe was installed into the chimney and connected to the sampler inlet. The probe heater and thermocouple were plugged into the umbilical.

Finally, the inlet and probe heaters were turned on and monitored with the readout on the control console, adjusting for 230°F.

Gas Analyzers - Gas analyzers were turned on and allowed to warm up for 30 minutes. Then, before each test, they were calibrated with span gas and checked at the completion. Nitrogen gas was also used to zero analyzers at the beginning and end of each run. From Run #4 on, the CO_2 meter would not calibrate to zero with nitrogen gas so the zero and span point keys were adjusted to compensate and the results were adjusted accordingly.

Platform Balance - A certified weight was placed on the platform balance at the beginning and end of each test run.

Barometer Pressure - A mercurial barometer at OMNI's laboratory was used for low elevations. During high elevation tests, the barometer pressure was taken from the mercurial barometer at the Suville Airport.

Hydrocarbon/Aldehyde Tube Sample - The hydrocarbon canister and the aldehyde tube sampler were operated in accordance with instructions provided by EPA. Start and stop times were recorded along with flow rates and initial and final pressure measurements. No additional information on calibration was provided.

The ANOVA test matrix shown in Table 14 is developed to conduct the statistical analysis for the one-half factorial experimental test design. Table values are used to determine contrasts which in turn are used to calculate effect. Columns AB/CD, AC/BD, and AD/BC represent the fuel × stove, the fuel × altitude, and the fuel × rate values. The test matrix was evaluated to determine the effects of stove variables on emissions performance using modified analysis of variance (ANOVA) principles. A Yates table was used to complete the test matrix for ANOVA analysis.[9] The conventional stove test matrix represented $^{3}/_{4}$ of a 2^3 experiment, excluding high and low burn rates using oak at a higher altitude (Appendix B). The catalytic stove was used to provide selected data expected from the Boise area: high and low burn rates using pine fuel at a higher altitude.

Table 14. ANOVA Test Matrix

Run No.	Sample Code	Fuel (A)	Stove (B)	Altitude (C)	Burnrate (D)	AB CD	AC BD	AD BC
1,3	SOLL	1 (oak)	1 (conv.)	1 (low)	-1 (low)	1	1	-1
2,4	SOLH	1 (oak)	1 (conv.)	1 (low)	1 (high)	1	1	1
6,14	SPLL	-1 (pine)	1 (conv.)	1 (low)	-1 (low)	-1	-1	1
5,16	SPLH	-1 (pine)	1 (conv.)	1 (low)	1 (high)	-1	-1	-1
9,10	SPHL	-1 (pine)	1 (conv.)	-1 (high)	-1 (low)	-1	1	1
7,8	SPHH	-1 (pine)	1 (conv.)	-1 (high)	1 (high)	-1	1	-1
12	EPHL	-1 (pine)	-1 (cat.)	-1 (high)	-1 (low)	1	1	-1
13	EPHH	-1 (pine)	-1 (cat.)	-1 (high)	1 (high)	1	1	-1

To facilitate the use of ANOVA procedures, main effects were calculated for test conditions of the conventional stove and the catalytic stove separately. Replicate runs were entered as the mean of paired data for each test condition. Where only one datum was available the single value was entered in place of the missing replicate. Tests were run to determine main effects of test variables on the parameters of particulate material, PAH, VOC, CO and inorganic material. ANOVA tests were conducted on all units of measure: concentration (mass/volume), emission rate (mass/time) and emission factor (mass/mass fuel). Main effects were calculated at 99%, 95%, and 90% confidence bounds (CB). Tables 15, 16, and 17 list all main effects at each confidence bound. Computer printouts of parameters which showed main effects at the 99% CB are shown in Appendix C. Printouts of main effects at the 95% CB are shown in Appendix D, and main effects at the 90% CB are shown in Appendix E. Appendix F shows all parameters for which the confidence bound for main effects was less than 90%.

In many cases, the large degree of variability between replicate runs made identifying "real" main effects difficult. Natural variability in combustion conditions was exacerbated by the cold-to-cold burn cycles used in this testing, but is believed to be representative of typical stove use.

Main Effects – 99% CB

Conventional Stove – Most of the main effects at the 99% CB were attributable to changes in fuel and burn rate (Table 15). The altitude variable did not show any main effects at the 99% CB, and few effects were attributable to stove type. Some main effects were observed as expected, such as an increase in stack flow rate and stack gas temperature at high burn rates.

Oak fuel showed lower concentrations of CO and CO_2 compared to the pine fuel at the 99% CB with strong significance ratios. (The significance ratio represents the "strength" of the main effect at a specific confidence bound; the greater the absolute value, the greater certainty that the main effect is real at that confidence bound.) Oxygen concentrations were higher with oak fuel, which may account for the higher stack flow rates recorded with oak fuel (because of higher excess air). The use of oak fuel resulted in decreases in the total measured PAH compound concentration ($-58{,}610\ \mu g/m^3$) and emission rate (−849 mg/hr) (with significance ratios of −1.0 and −1.2, respectively) (Figure 16). Based on the analysis of fuel composition (Table 2), the pine fuel had about 5% higher volatile fraction than the oak. It also averaged about 20% lower moisture (Table 4) than the oak. Both of these factors could contribute to a more rapid release of volatile gases from the fuel during combustion. Oak fuel also resulted in an increase in the concentration, emission rate, and emission factor for potassium (K) and lead (Pb), although lead values were very low.

Table 15. Main Effects (99% Confidence Bound) of Variables on Stove Emissions

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)b	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
Burn Rate (kg/hr)			2.7 (1.4)					1.6 (1.2)	
Total Fuel Burned (kg)			1.4 (7.7)					1.2 (9.2)	
Stack Flow (m^3/hr)	1.1 (2.1)		2.8 (5.3)				1.3 (3.3)	1.9 (5.2)	
Stack Temperature (°C)			1.2 (75)						
CO (%)	−1.4 (−0.6)		1.2 (2.6)				2.3 (1.3)		
CO_2 (%)	−1.5 (−4.4)		1.4 (3.2)						
O_2 (%)	1.7 (4.5)		−1.4 (−3.2)						
PAH Compounds (ug/m^3)									
Pyrene									
Benzo(k)fluoranthene				−1.0 (−1,185)		1.4 (2,410)			
Dibenzo(a,h)anthracene					−1.0 (−105)				
Total GC/MS PAH	−1.0 (−58,610)				−1.2 (−100)	1.3 (113)			
PAH Compounds (mg/hr)									
Naphthalene	−1.1 (−367)								
Fluorene	−1.0 (−20)								
Phenanthrene					−1.0 (−22)				
Fluoranthene				−1.0 (−92)	−1.2 (−116)	1.3 (123)			
Pyrene				−1.0 (−25)	−1.3 (−32)	1.4 (35)			
Benzo(b)fluoranthene				−1.6 (−37)	−1.7 (−41)	2.1 (49)			
Benzo(k)fluoranthene						1.1 (10)			
Benzo(a)pyrene				−1.2 (−2)	−1.6 (−3)	1.9 (3)			
Benzo(g,h,i)perylene					−1.1 (−6)	1.4 (7)			
Dibenzo(a,h)anthracene			1.0 (7)						
Total GC/MS PAH	−1.2 (−849)			−1.3 (2)	−1.6 (−2)	1.7 (2)			

(continued)

Table 15. Main Effects (99% Confidence Bound) of Variables on Stove Emissions (cont.)

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)[b]	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
PAH Compounds (mg/kg)									
Phenanthrene						1.0 (48)			
Fluoranthene						1.1 (14)			
Pyrene				-1.2 (-12)		1.8 (19)			
Benzo(k)fluoranthene				-1.0 (-1)	-1.2 (-1)	1.9 (1)	-5.9 (-6)		
Benzo(a)pyrene						1.1 (3)	-1.1 (-4)		
Dibenzo(a,h)anthracene					-1.1 (-1)	1.3 (1)	-6.8 (-6)		
Inorganics (ug/m^3)									
K	1.2 (2,397)								
Ni			1.0 (3)	-1.3 (-4)					
Pb	2.0 (5)						-2.5 (-10)	-1.3 (-5)	1.3 (5)
Inorganics (mg/hr)									
K	1.3 (41)								
Ni			2.1 (0)	-2.4 (0)					
Pb	2.1 (0)						-1.8 (0)		
Inorganics (mg/kg)									
K	1.4 (24)								
Ni			1.1 (0)	-1.4 (-0)					
Pb	1.9 (0)						-1.9 (0)	-1.1 (0)	1.1 (0)

[a] Significance ratio = $\frac{\text{main effect value}}{\text{(std. dev.) (f-factor)}}$.

If the absolute value of the significance ratio is >1.0, the difference between measured parameters is considered a main effect. The f-factor increases with higher confidence bounds, requiring a greater difference between two conditions of the variable to be considered significant. The significance ratio is shown first, and the main effect value is shown in parentheses ( )

[b] A positive value indicates an increase in the parameter when oak fuel was used relative to pine. A negative value indicates a decrease.

[c] A positive value indicates an increase in the parameter when testing was conducted at the low elevation (80 meters) site relative to the high elevation (800 meters) site. A negative value indicates a decrease.

[d] A positive value indicates an increase in the parameter when testing was conducted at a high burn rate relative to a low burn rate. A negative value indicates a decrease.

[e] A positive value indicates an increase in the parameter when testing was conducted with oak at a low altitude, relative to pine at high altitude. A negative value indicates a decrease.

[f] A positive value indicates an increase in the parameter when testing was conducted with oak at a high burn rate relative to pine at a low burn rate. A negative value indicates a decrease.

[g] A positive value indicates an increase in the parameter when testing was conducted at low altitude at a high burn rate relative to high altitude at a low burn rate.

[h] A positive value indicates an increase in the parameter when testing was conducted with the conventional stove relative to the catalytic stove. A negative value indicates a decrease.

[i] A positive value indicates an increase in the parameter when testing was conducted with the conventional stove at a high burn rate relative to the catalytic stove at a low burn rate.

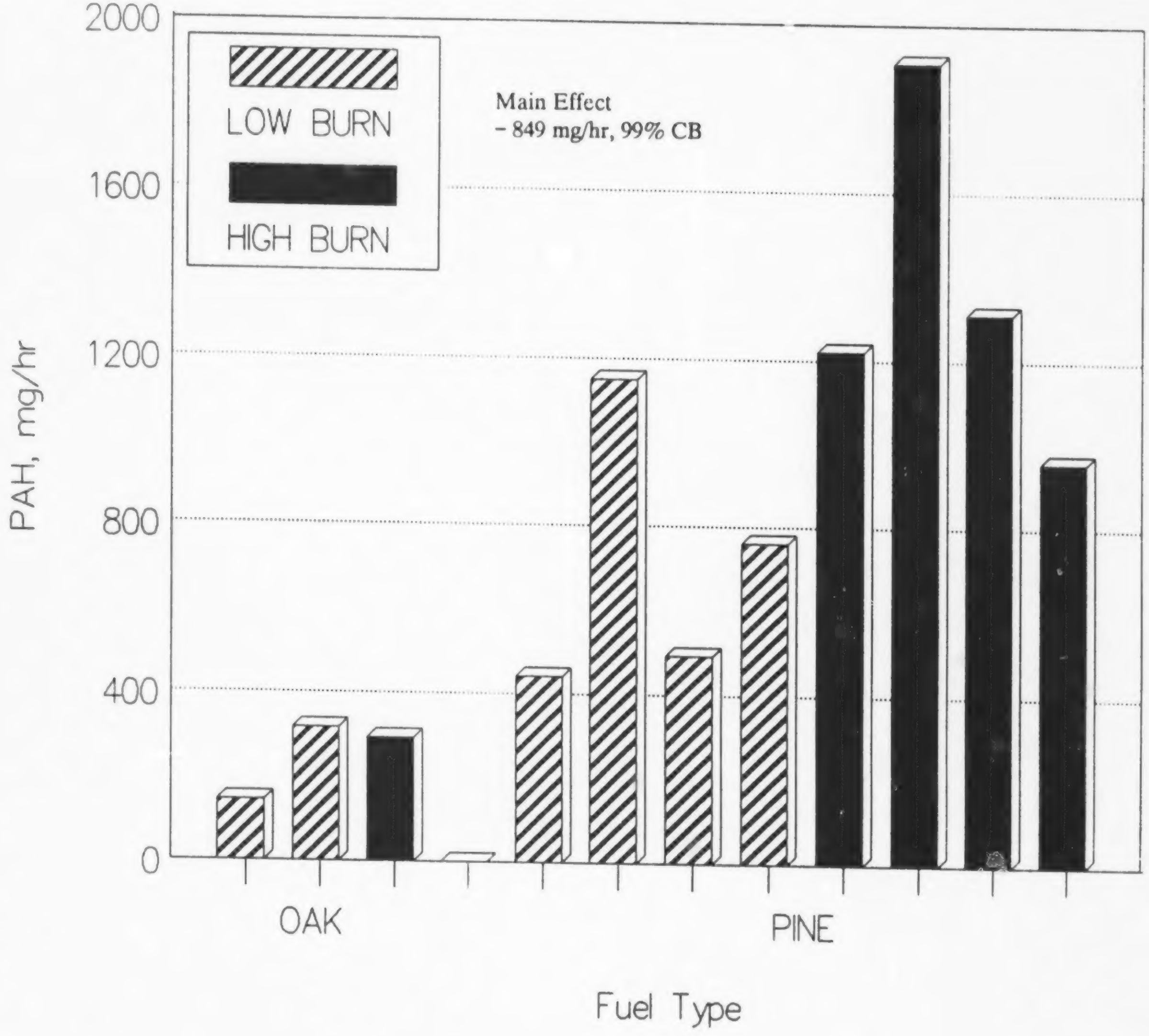

Figure 16. Effect of fuel type on PAH emissions (conventional stove).

The high burn rates showed a number of main effects, especially in stove process parameters. High burn rates showed significant increases relative to low burn rates in measured burn rate, total fuel burned, stack flow, stack temperature, and concentrations of CO and CO_2. Oxygen concentrations decreased at higher burn rates. The emission rate of benzo(g,h,i)perylene increased slightly (at a significance factor of 1.0) at high burn rates. The concentration, emission rate and emission factor for nickel increased marginally with the higher rates.

The interaction of the fuel variable with altitude and burn rate, and the interaction of altitude with burn rate, showed slight to moderate main effects for the emission rate and emission factor for several individual PAH compounds. Decreases in the concentration, emission rate, and emission factor for nickel were also shown in the fuel/altitude interaction.

Catalytic Stove – Main effects attributable to the use of the catalytic stove were limited at the 99% confidence bound. Stack flows and average CO concentrations (%) were lower at significance ratios of 1.3 and 2.3, respectively. Emission factors for three PAH compounds (including benzo(a)pyrene) increased marginally when the catalytic stove was used, although significance factors were generally high. The concentration, emission rate, and emission factor for lead (Pb) increased marginally with the catalytic stove compared to the conventional stove.

Burn rate main effects with the catalytic stove were limited to burn rate, total fuel burned, stack flow rate, and the concentration and emission factor for lead. The stove/burn rate interaction showed marginal main effects for the concentration and emission factor of lead.

Main Effects – 95% CB

Conventional Stove – Main effects at the 95% confidence bound include all the main effects identified at the 99% CB, but with higher significance ratios (Table 16). Main effects at the 95% CB attributable to oak fuel (compared with pine) which were not identified at the 99% CB include small to moderate decreases in the concentrations, emission rate, and emission factor of a number of individual PAH compounds. The emission factor for total identified PAH compounds decreased at significance ratio of −1.5. Phosphorus ($\mu g/m^3$, mg/hr, and mg/kg) increased marginally with oak, and benzene and toluene showed marginal decreases in emission rates and emission factors.

Low elevation testing showed a slight (0.3% absolute) decrease in CO concentration (%), and marginal decreases in the aluminum concentration and emission rate. The burn rate variable yielded the only main

Table 16. Main Effects (95% Confidence Bound) of Variables on Stove Emissions

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)b	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
Burn Rate (kg/hr)	-1.0 (-0.3)		j			-1.3 (-0.4)	1.5 (0.6)	j	1.3 (0.6)
Stack Flow (m^3/hr)	j		j		-1.3 (-1.5)		j	j	1.3 (2.1)
Stack Temperature (°C)			j			-1.0 (-39)		1.1 (61)	
CO (%) (g/m^3)	j	-1.1 (-0.3)	j			-1.1 (-0.3)	j 1.2 (14.5)	1.5 (0.5)	
CO_2 (%)	j		j		1.0 (1.8)	j		1.1 (2.8)	
O_2 (%)	j		j			1.0 (1.5)		-1.0 (-2.3)	
Particulate Material (g/kg)									
Total Capture			-1.0 (-17)						
Gravimetric			-1.0 (-11)						
PAH Compounds (ug/m^3)									
Naphthalene	-1.5 (-23,567)								
Fluorene	-1.3 (-1,346)								
Phenanthrene	-1.0 (-4,812)								
Pyrene	-1.1 (-1,185)					1.3 (5,888)			
Anthracene	-1.4 (-1,050)				-1.6 (-1,628)	j			
Fluoranthene	-1.0 (-1,248)				-1.0 (-762)				
Benzo(p)pyrene	-1.0 (-856)			-1.0 (-1,154)	-1.0 (-1,251)	1.4 (1,724)			
Benzo(b)fluoranthene									
Benzo(k)fluoranthene	-1.1 (-75)					1.1 (584)			
Benzo(a)pyrene				-1.3 (-87)	j	j			
Dibenzo(a,h)anthracene				-1.0 (-245)	-1.0 (-246)	1.6 (391)			
Total GC/MS PAH	j			-1.6 (-81)	j	j			
PAH Compounds (mg/hr)									
Naphthalene	j		1.4 (272)						
Fluorene	j								
Phenanthrene	-1.2 (-69)				j	1.5 (19)	1.1 (20)		
Anthracene	-1.4 (-17)			j	j	j			
Fluoranthene	-1.2 (-18)				j	j			
Pyrene	-1.2 (-16)			j	j	j			
Benzo(a)anthracene				j	j	j			
Benzo(e)pyrene	-1.2 (-11)			-1.2 (-27)	-1.2 (-26)	1.4 (30)			
Benzo(b)fluoranthene	-1.0 (-5)			-1.0 (9)		1.5 (13.3)			
Benzo(k)fluoranthene	-1.3 (-1.1)			-1.2 (-6)	-1.1 (-6)	j			
Benzo(a)pyrene				j	j	j			
Benzo(g,h,i)perylene	-1.1 (-4)		j	-1.6 (-5)	j	j			
Dibenzo(a,h)anthracene				-1.5 (-6)					
Total GC/MS PAH	j			j	j -1.0 (-428)	j			

(continued)

Table 16. Main Effects (95% Confidence Bound) of Variables on Stove Emissions (cont.)

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)b	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
PAH Compounds (mg/kg)									
Naphthalene	-1.5 (144)								
Fluorene	-1.0 (-6)								
Phenanthrene					-1.1 (-7)	1.4 (9)			
Anthracene	-1.3 (-6)			-1.1 (-31)	-1.2 (-34)	j			
Fluoranthene					-1.3 (-6)	1.4 (6)			
Pyrene	-1.0 (-7)			-1.1 (-8)	-1.2 (-9)	j			
Benzo(b)fluoranthene				j	j	j			
Benzo(k)fluoranthene	-1.1 (0)					1.2 (5)	j	-1.0 (-1)	
Benzo(a)pyrene				j	j	j	j		
Benzo(g,h,i)perylene				-1.0 (-2)	-1.1 (-2)	j	-1.5 (-5)		
Dibenzo(a,h)anthracene							j		
Total GC/MS PAH	-1.5 (-329)			-1.5 (-1)	j	j	1.3 (394)		
Inorganics (ug/m^3)									
Al		-1.0 (-600)							
Cd								-1.0 (-4)	
K	j								
Ni			j	j					
PO_4	1.2 (29)								
Pb	j						j	j	j
Inorganics (mg/hr)									
Al		-1.1 (-10)							
K	j								
Ni			j	j					
PO_4	1.5 (1)	-1.0 (0)							
Pb	j						j	-1.2 (0)	1.2 (0)
Inorganics (mg/kg)									
K	j								
Ni			j	-1.4 (0)					
PO_4	1.2 (0)								
Pb	j						j	j	j
Sn			-1.0 (0)						

(continued)

Table 16. Main Effects (95% Confidence Bound) of Variables on Stove Emissions (cont.)

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)b	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
Hydrocarbons (ug/m^3)									
Benzene	-1.3 (-121)								
Methyl ethyl ketone						1.1 (34)			
2-methyl furan								-1.5 (-135)	
Hydrocarbons (mg/hr)									
Acetylene			1.2 (1)				1.1 (1)		
Benzene	-1.3 (-2)								
Toluene	-1.0 (-1)								
Methyl ethyl ketone					-1.2 (0)	1.3 (1)			
2-methyl furan								-1.2 (-1)	
O-xylene				-1.1 (0)		1.3 (0)			
Hydrocarbons (mg/kg)									
Acetylene			1.2 (1)				1.1 (1)		
Benzene	-1.3 (-1)								
Toluene	-1.0 (0)								
Methyl ethyl ketone					-1.2 (0)				
2-methyl furan								-1.2 (-1)	
O-xylene				-1.1 (0)		1.3 (0)			

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[a] Significance ratio = $\frac{\text{main effect value}}{(\text{std. dev.})\ (\text{f-factor})}$.

If the absolute value of the significance ratio is >1.0, the difference between measured parameters is considered a main effect. The f-factor increases with higher confidence bounds, requiring a greater difference between two conditions of the variable to be considered significant. The significance ratio is shown first, and the main effect value is shown in parentheses ( ).

[b] A positive value indicates an increase in the parameter when oak fuel was used relative to pine. A negative value indicates a decrease.

[c] A positive value indicates an increase in the parameter when testing was conducted at the low elevation (80 meters) site relative to the high elevation (800 meters) site. A negative value indicates a decrease.

[d] A positive value indicates an increase in the parameter when testing was conducted at a high burn rate relative to a low burn rate. A negative value indicates a decrease.

[e] A positive value indicates an increase in the parameter when testing was conducted with oak at a low altitude, relative to pine at high altitude. A negative value indicates a decrease.

[f] A positive value indicates an increase in the parameter when testing was conducted with oak at a high burn rate relative to pine at a low burn rate. A negative value indicates a decrease.

[g] A positive value indicates an increase in the parameter when testing was conducted at low altitude at a high burn rate relative to high altitude at a low burn rate.

[h] A positive value indicates an increase in the parameter when testing was conducted with the conventional stove relative to the catalytic stove. A negative value indicates a decrease.

[i] A positive value indicates an increase in the parameter when testing was conducted with the conventional stove at a high burn rate relative to the catalytic stove at a low burn rate.

[j] Significant at the 99% confidence bound. See Table 15 for values.

effect attributable to particulate material at a 95% CB or higher; the emission factor for total particulate and the grav fraction were slightly lower at the higher burn rates at a significance ratio of −1.0.

The fuel/altitude interaction showed decreases in several individual PAH compounds ($\mu g/m^3$, mg/hr, mg/kg). The fuel/burn rate interaction (oak/high burn rate) yielded similar results, with additional main effects of lower stack flow rates, lower CO concentrations (g/m^3), and higher CO_2 concentrations (%). Significance factors were low to moderate, and main effect values were generally small relative to sample values.

The altitude/burn rate interaction (low elevation/high burn rate) showed decreases in burn rate, stack temperature, and CO concentration. The concentrations, emission rates, and emission factors of several individual PAH compounds showed low to moderate main effects. Increases of methyl ethyl ketone and o-xylene also showed nominal main effects.

Catalytic Stove – At the 95% confidence bound, main effects included a decrease in burn rate with the catalytic stove relative to the conventional stove. Total measured PAH compounds (mg/kg) showed a decrease with the catalytic stove (394 mg/kg, significance factor of 1.3). Nominal decreases in the emission rate and emission factor were shown for acetylene.

The burn rate variable showed higher stack temperatures, CO (%), and CO_2 (%). Other effects were minor. The stove/burn rate interaction showed few main effects.

Main Effects – 90% CB

Conventional Stove – The concentration, emission rate, and emission factor of several individual PAH compounds decreased at the 90% CB when oak rather than pine fuel was used. Most of these main effects showed relatively small values. Toluene concentrations also dropped with the use of oak fuel (significance ratio of −1.2). Other main effects were nominal.

Testing at the low altitude site caused a slight decrease (−0.9 m^3/hr) in average stack flow rates. The emission rate of total identified PAH compounds increased at low elevations (main effect of 327 mg/hr, significance ratio of 1.1), as did naphthalene (main effect of 168 mg/hr, significance ratio of 1.2). The emission factor for naphthalene also increased. Slight decreases in the concentration, emission rate, and emission factor of several inorganics occurred with low elevation testing. This may be due to lower stack flow rates (and ash entrainment) or different fuel composition. Butenes showed a slight increase in concentration with low elevation testing.

Table 17. Main Effects (90% Confidence Bound) of Variables on Stove Emissions

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)b	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
Burn Rate (kg/hr)	k		j			k	k	j	k
Stack Flow (m³/hr)	j	−1.1 (−0.9)	j	k			j	j	k
Stack Temperature (°C)			j			k		k	
CO (%)	j	k	j			k	j	k	
(g/kg)							1.1 (89)		
CO₂ (%)	j		j		k	k		k	
O₂ (%)	j		j		−1.1 (−1.2)	k		k	−1.0 (−1.6)
Particulate Material (g/m³)									
Total Capture			−1.0 (−1.4)						
Particulate Material (g/kg)									
Total Capture			k						
Gravimetric			k						
TCO			−1.2 (−2.5)						
Gravimetric + TCO			−1.3 (−13.5)						
PAH Compounds (ug/m³)									
Naphthalene	k								
Acenaphthylene	−1.0 (−10,263)								
Fluorene	k				−1.0 (−756)		1.1 (1,138)		
Phenanthrene	k			−1.2 (−4,266)	−1.3 (−4,368)	k			
Anthracene	k				k	1.2 (672)			
Fluoranthene	k			k	k	k			
Pyrene	k			j	k	j			
Benzo(a)anthracene	−1.2 (−1,504)			−1.0 (−1,282)					
Benzo(e)pyrene	k					1.1 (692)			
Benzo(b)fluoranthene	−1.1 (−397)					k			
Benzo(k)fluoranthene	k			k	j	j			
Benzo(a)pyrene	−1.0 (−190)			k	k	k			
Benzo(g,h,i)perylene	−1.2 (−332)	−1.1 (−295)							
Dibenzo(a,h)anthracene				k	j	j			
Total GC/MS PAH	j								

(continued)

Table 17. Main Effects (90% Confidence Bound) of Variables on Stove Emissions (cont.)

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)b	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
PAH Compounds (mg/hr)									
Naphthalene	j	1.2 (168)	k		−1.1 (−147)			1.2 (238)	
Acenaphthylene	−1.1 (−129)						1.0 (166)		
Fluorene	j				j	k	k		
Phenanthrene	k			j	j	j			
Anthracene	k			−1.1 (−9)	j	k	1.1 (13)		
Fluoranthene	k			j	j	j			
Pyrene	k			j	j	j			
Benzo(a)anthracene	−1.3 (−20)			k	k	k			
Benzo(e)pyrene	k			k	−1.2 (−8)	k	1.1 (11)		
Benzo(b)fluoranthene	k			k	k	j	1.0 (6)		
Benzo(k)fluoranthene	k			j	j	j	1.1 (1)		
Benzo(a)pyrene	−1.1 (−3)			k	j	j			
Benzo(g,h,i)perylene	k			k	j				
Dibenzo(a,h)anthracene				j	j	j			
Total GC/MS PAH	j	1.1 (327)	1.2 (381)		k	1.0 (304)	1.0 (432)		
PAH Compounds (mg/kg)									
Naphthalene	k	1.1 (74)							
Fluorene	k				k	k	1.2 (8)		
Phenanthrene	−1.2 (−26)			k	k	j			
Anthracene	k			−1.0 (−3)	k	k	1.0 (4.6)		
Fluoranthene	−1.2 (−7)			k	k	j			
Pyrene	k			j	j	j			−1.0 (−7)
Benzo(a)anthracene	−1.1 (−9)			−1.1(−9)		1.3 (10)			
Benzo(e)pyrene	−1.2 (−5)		−1.0 (−5)			k			
Benzo(b)fluoranthene			−1.0 (−3)			k			
Benzo(k)fluoranthene	k		−1.0 (−0.3)	j	j	j	j	k	
Benzo(a)pyrene				−1.4 (−2)	k	j	j		
Benzo(g,h,i)perylene	−1.2 (−2)		1.0 (2)	−1.2 (−2)			k		
Dibenzo(a,h)anthracene				k	j	j	j		
Total GC/MS	k						k		

(continued)

Table 17. Main Effects (90% Confidence Bound) of Variables on Stove Emissions (cont.)

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)[b]	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
Inorganics (ug/m^3)									
Al		k					1.1 (652)		
K	j								
Mg		−1.0 (−131)							
Ni			j	j					
PO$_4$	k	−1.3 (−24)							
Pb	j						j	j	j
Sn			−1.2 (−11)						
Inorganics (mg/hr)									
Al		−1.5 (−10)	1.1 (7)			−1.1 (−7)	1.2 (11)		
Ca		−1.0 (−7)							
Cd								−1.2 (0)	
K	j		1.1 (16)						
Mg		−1.1 (−2.0)							
Mn	1.1 (0)								
Ni			j	j					
PO$_4$	k	k							
Pb	j						j	k	k
Inorganics (mg/kg)									
Al		−1.2 (−4)							
Cd			−1.0 (0)					−1.2 (0)	
K	j								
Ni			j	j					
PO$_4$	k	−1.2 (0)							
Pb	j						j	j	j
Sn	1.0 (0)		k		−1.0 (0)				
Hydrocarbons (ug/m^3)									
Acetylene							1.0 (50)		
Butenes		1.0 (46)							
Pentenes			−1.0 (−37)						
Benzene	k								
Toluene	−1.2 (−42)								
Methyl ethyl ketone				−1.1 (−24)	−1.2 (−27)	k			
2-methyl furan			−1.1 (−53)				−1.1 (−75)	k	1.2 (77)
2,5-dimethyl furan			−1.1 (−13)						
Furfural			−1.1 (−35)						
O-xylene			−1.0 (−11)	−1.0 (−11)		1.0 (11)			

(continued)

Table 17. Main Effects (90% Confidence Bound) of Variables on Stove Emissions (cont.)

Parameter	Significance Ratio[a] for Conventional Stove						Significance Ratio for Catalytic Stove		
	Fuel (A) (pine to oak)b	Altitude (C) (high to low)[c]	Burn Rate (D) (low to high)[d]	AC[e]	AD[f]	CD[g]	Stove (B) (catalyst to conventional)[h]	Burn Rate (D) (low to high)[d]	BD[i]
Hydrocarbons (mg/hr)									
Acetylene			1.6 (1)				k		
Benzene	k								
Toluene	k								
Furan					−1.0 (−1)				
Methyl ethyl ketone				−1.2 (0)	k	k			
2-methyl furan			−1.0 (−1)					k	
2,5-dimethyl furan			−1.0 (0)						
Furfural			−1.0 (0)						
O-xylene			−1.0 (0)	k		k			
Hydrocarbons (mg/kg)									
Acetylene			k						
Benzene	k						k		
Toluene	k								
Furan					−1.0 (0)				
Methyl ethyl ketone				−1.2 (0)	k	k			
2-methyl furan			−1.0 (0)					k	
2,5-dimethyl furan			−1.0 (0)						
Furfural			−1.0 (0)						
O-xylene			−1.0 (0)	k		k			

[a] Significance ratio = $\frac{\text{main effect value}}{\text{(std. dev.) (f-factor)}}$.

If the absolute value of the significance ratio is >1.0, the difference between measured parameters is considered a main effect. The f-factor increases with higher confidence bounds, requiring a greater difference between two conditions of the variable to be considered significant. The significance ratio is shown first, and the main effect value is shown in parentheses ( ).

[b] A positive value indicates an increase in the parameter when oak fuel was used relative to pine. A negative value indicates a decrease.

[c] A positive value indicates an increase in the parameter when testing was conducted at the low elevation (80 meters) site relative to the high elevation (800 meters) site. A negative value indicates a decrease.

[d] A positive value indicates an increase in the parameter when testing was conducted at a high burn rate relative to a low burn rate. A negative value indicates a decrease.

[e] A positive value indicates an increase in the parameter when testing was conducted with oak at a low altitude, relative to pine at high altitude. A negative value indicates a decrease.

[f] A positive value indicates an increase in the parameter when testing was conducted with oak at a high burn rate relative to pine at a low burn rate. A negative value indicates a decrease.

[g] A positive value indicates an increase in the parameter when testing was conducted at low altitude at a high burn rate relative to high altitude at a low burn rate.

[h] A positive value indicates an increase in the parameter when testing was conducted with the conventional stove relative to the catalytic stove. A negative value indicates a decrease.

[i] A positive value indicates an increase in the parameter when testing was conducted with the conventional stove at a high burn rate relative to the catalytic stove at a low burn rate.

[j] Significant at the 99% confidence bound. See Table 15 for values.

[k] Significant at the 95% confidence bound. See Table 16 for values.

Higher burn rates showed significantly lower concentrations of total particulate material as a main effect (main effect of −1.4 g/m^3, significance ratio of −1.0). Decreases of emission factors for TCO and grav + TCO were also moderately significant at the 90% CB. The emission rate for total identified PAH compounds increased by 381 mg/hr (significance ratio of 1.2), while marginal decreases (and an increase) were recorded for several individual PAH emission factors.

The fuel/altitude (oak/low elevation) and fuel/burn rate interaction (oak/low burn rate) resulted in similar main effects – relatively small decreases in the concentration, emission rate, and emission factor for several individual PAH compounds and hydrocarbons. The altitude/burn rate interaction (low elevation/high burn rate) showed an increase in the emission rate for total PAH compounds. A few other minor main effects were also noted.

Catalytic Stove – Tests conducted with the catalytic stove showed a lower emission factor (89 g/kg) for CO when compared to the conventional stove. Slight decreases in the concentration, emission rate, and emission factor for several individual PAH were shown as main effects. Total identified PAH compounds showed a significant decrease (432 mg/hr), but with a significance ratio of just 1.0 due to data variability. A few other nominal main effects were recorded. Other variables (burn rate and the stove/burn rate interaction) showed a few minor main effects.

Quality Assurance

A Quality Assurance Project Plan (QAPP) was prepared prior to the testing activities of this project. The QAPP was reviewed and approved by EPA. All sampling methods, data reporting, and QA procedures specified by the QAPP were followed.

Data Completeness

Data completeness is defined as the percentage of data planned for collection for which valid data was collected. Data completeness objectives for most pollutant parameters was 95%. Actual data completeness is listed in Table 18.

Data completeness objectives were not met in four areas: mass of particles, PAHs, aldehydes, and flue gases. The loss of particle data in Run 2 and Run 5 does not significantly affect the completeness of the data since each of these runs had a duplicate run with acceptable data. The loss of the associated variability between duplicates was also not significant because two other runs were also duplicated.

The loss of the PAH data in the probe rinse on Runs 1 through 8 is not significant to the overall completeness of the data, since the probe rinse from Runs 9, 10, 11, 14, and 16 was analyzed and the level of loading of the probe rinse could be estimated for the other runs.

The flue gas data did not meet data completeness objectives but the effect is not significant. Only Run 2 data was affected and the data acquired from other runs is consistent. The additional data would have no affect on results.

In contrast to the above effects, the aldehyde failure has a major impact on the conclusions of this experiment, since aldehydes are known to be present in stove emissions and could be significantly affected by the variables present.

Data Precision

Data precision is determined by the following equation:

$$P = \frac{\text{Max} - \text{Min}}{\text{Mean}} \quad 100,$$

Where: Max = maximum value;
Min = minimum value; and
Mean = mean of two replicates.

Systemic data precision (based on all factors affecting data reproducibility) for various data parameters are listed in Table 19.

Analytical work was performed by contracted laboratories, which reported that all specified calibrations and QA procedures were followed.

Internal Quality Control

Information on the internal quality control activities associated with the analysis of the WSDSS and aldehyde/VOC samples conducted by EPA was not provided. It is assumed that the Quality Control activities met the requirements of the QAPP plan as approved by EPA.

Table 18. Data Completeness

Parameter	Valid Runs	Data Completeness	Explanatory Notes
Mass particles			
Total	12	86%[a,b]	Run 5 grav sample lost; Run 2 short
Condensible (grav)	12	86%[a,b]	Run 5 grav sample lost; Run 2 short
Semivolatile (TCO	13	93%[b]	Run 2 short
PAH	8	43%[c]	Runs 1 – 8 missing probe rinse
VOC	14	100%	
Aldehydes	0	0%[d]	Data did not meet QA objectives
Elemental emissions	14	100%	
Fuel characteristics[e]	14	100%	
Ash residue	14	100%	
Flue gases	13	93%[b]	Run 2 short
Burn rate	14	100%	

a – A mantle heater control malfunctioned during laboratory processing of the grav portion of Run 5. The sample was destroyed.

b – A power failure was experienced before the completion of Run 2, causing all sampling equipment to go off. Data are not considered representative of defined test conditions because of the premature end to testing.

c – A methanol rinse was used on the probe rinse prior to a dichloromethane rinse on Runs 1 – 8. Analysis for PAH was not conducted on these samples. However, all other samples collected on the conventional stove showed the probe rinse to contain 1.3% to 4.0% of the total PAH mass, averaging 2.5%.

d – Dual aldehyde trains were used at different sampling rates to avoid breakthrough. Results from the dual trains showed considerable variability. Subsequent tests revealed DNPH exhaustion and probable breakthrough for many runs.

e – Includes proximate, ultimate and elemental analyses. Also includes fuel moisture.

Table 19. Data Precision (Systemic)

Parameter	Average Precision (%)	Explanatory Notes
Mass particles (g/hr)		
Total	54%	Excludes Runs 2, 4, 5 and 16
Condensible (grav)	63%	Excludes Runs 2, 4, 5 and 16
Semivolatile (TCO)	63%	Excludes Runs 2 and 4
PAH total (mg/hr)	57%	Based on Runs 9, 10, 12 and 13
VOC total (mg/hr)	50%	Excludes Runs 2 and 4
Stack flow	15%	Excludes Runs 2 and 4
Burn rate	17%	Excludes Runs 2 and 4
Gas		
CO	15%	All Runs
CO_2	12%	
O_2	10%	
Stack temp	20%	All Runs
Fuel moisture	5%	All Runs
Fuel burned	10%	Excludes Runs 2 and 4
Elemental analysis	90%	All Runs

General

No major problems were encountered with data collection or analysis. Specific events which caused "flagged" or lost data area addressed below:

1. Run 2 – Electrical power to the test lab was lost at 246 minutes into the test run. The test ended with 1.9 kg fuel remaining (12% of total mass burned) and a flue temperature of about 176°C. Run 4, the replicate of Run 2, ended with 3.5% of the fuel mass remaining and a flue temperature of 65°C. Data from Run 2 was presented but flagged as nonrepresentative.

2. Run 5 – A heating mantle controller malfunctioned in the laboratory, resulting in overheating of the grav fraction of the test. Because the grav fraction is used in total particulate determinations, both total and grav particulate values were affected.

3. The probe rinses from Runs 1 through 8 received a methanol rinse, followed by a dichloromethane rinse. These samples were not analyzed for PAH compounds because of concerns of reactivity of some PAH compounds in the methanol. Probe rinses from Runs 9 through 16 were processed with the dichloromethane rinse first. The probe rinse fraction of Runs 9, 10, 14 and 16 (conventional stove runs) showed the probe rinse fraction to average 2.5% of the total PAH mass, ranging from 1.3% to 4.0%. For this reason, total PAH values for Runs 1 through 8 were factored up by 2.5% to account for the missing probe rinse mass. These values were flagged with notes explaining the corrections to the data.

4. The probe rinse gravimetric samples from Runs 14 and 16 did not meet replicate weighing QA standards, as weight loss between weighings was greater than acceptable limits. Due to the large total mass of the samples, these values were used, with the last weighing value used as the true value.

5. No aldehyde values were reported, as values from the dual sampling trains did not meet QA goals. Probable cause for lack of agreement between trains was breakthrough of aldehyde compounds from high concentrations in flue gases.

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APPENDIX A. TEST DATA

	RUN 1	RUN 3	RUN 2	RUN 4	RUN 6	RUN 14	RUN 5	RUN 16	RUN 9	RUN 10	RUN 7	RUN 8	RUN 12	RUN 13
BURN RATE (kg/hr)	1.35	1.28	2.59	2.09	1.66	1.67	2.31	2.92	1.18	1.63	3.18	3.14	1.33	1.94
DILUTION RATIO														
SAMPLE VOLUME (M3)	3.316	3.331	1.590	3.386	3.081	3.344	2.979	2.966	3.579	2.870	2.801	2.821	3.661	3.519
TOTAL FUEL BURNED (KG)	11.0	11.1	10.6	17.4	12.3	12.3	16.8	21.1	8.9	11.7	23.1	22.3	10.7	16.6
STOVE DATA														
STACK FLOW (m3/hr)	15.368	14.042	18.872	17.248	11.589	10.642	14.535	20.252	11.077	12.018	18.986	18.652	10.305	13.384
STACK TEMPERATURE (C)	142	118	211	158	171	119	128	195	90	119	204	195	103	129
CO AVERAGE (%)	0.93	1.16	1.55	1.25	1.74	1.78	1.99	1.64	1.88	1.64	2.19	2.48	0.49	0.96
CO2 AVERAGE(%)	6.5	6.6	10.8	9.5	12.0	13.4	13.4	12.2	8.0	11.3	14.1	13.9	12.2	13.4
O2 AVERAGE (%)	13.9	13.4	9.6	11.0	8.0	7.9	6.8	7.3	11.8	8.7	6.2	6.5	8.0	7.3
PARTICULATE MASS														
TOTAL CAPTURE (g)	6.805	8.229	3.671	3.113	2.899	9.650	0.000	3.301	16.371	2.664	1.899	1.715	2.199	2.115
GRAV (g)	4.0398	5.6201	2.4195	1.5064	1.3234	5.4656	0.0000	1.7765	10.1790	1.4647	0.9543	0.9913	1.2589	0.5844
TCO (g)	1.016	0.734	0.496	0.561	0.586	2.233	1.009	0.991	2.922	0.870	0.525	0.559	0.511	1.291
GRAV+TCO (g)	5.056	6.354	2.915	2.067	1.909	7.699	1.009	2.767	13.101	2.335	1.480	1.550	1.770	1.876
PARTICULATE CONC (g/m3)														
TOTAL CAPTURE(g/m3)	2.05	2.47	2.31	0.92	0.94	2.89	0.00	1.11	4.57	0.93	0.68	0.61	0.60	0.60
GRAV (g/m3)	1.22	1.69	1.52	0.44	0.43	1.63	0.00	0.60	2.84	0.51	0.34	0.35	0.34	0.17
TCO (g/m3)	0.31	0.22	0.31	0.17	0.19	0.67	0.34	0.33	0.82	0.30	0.19	0.20	0.14	0.37
GRAV+TCO (g/m3)	1.52	1.91	1.83	0.61	0.62	2.30	0.34	0.93	3.66	0.81	0.53	0.55	0.48	0.53
PARTICULATE EMISSION RATE (g/hr)														
TOTAL CAPTURE (g/hr)	31.54	34.69	43.57	15.86	10.90	30.71	0.00	22.54	50.67	11.16	12.87	11.34	6.19	8.04
GRAV (g/hr)	18.72	23.69	28.72	7.67	4.98	17.39	0.00	12.13	31.50	6.13	6.47	6.55	3.54	2.22
TCO (g/hr)	4.71	3.09	5.88	2.86	2.20	7.11	4.92	6.76	9.04	3.64	3.56	3.69	1.44	4.91
GRAV+TCO (g/hr)	23.43	26.79	34.60	10.53	7.18	24.50	4.92	18.89	40.55	9.78	10.03	10.25	4.98	7.13
PARTICULATE EMISSION FACTOR (g/kg)														
TOTAL CAPTURE (g/kg)	23.36	27.10	16.82	7.59	6.57	18.39	0.00	7.72	42.94	6.84	4.05	3.61	4.65	4.15
GRAV (g/kg)	13.87	18.51	11.09	3.67	3.00	10.42	0.00	4.15	26.70	3.76	2.03	2.09	2.66	1.15
TCO (g/kg)	3.49	2.42	2.27	1.37	1.33	4.26	2.13	2.32	7.67	2.23	1.12	1.18	1.08	2.53
GRAV+TCO (g/kg)	17.36	20.93	13.36	5.04	4.33	14.67	2.13	6.47	34.36	6.00	3.15	3.26	3.75	3.68
	Run 1	Run 3	Run 2	Run 4	Run 6	Run 14	Run 5	Run 16	Run 9	Run 10	Run 7		Run 12	Run 13
ACCUREX GC/MS PAH ANALYSIS RESULTS (ug COLLECTED)														
NAPHTHALENE	12535	21530	25058	28332	50375	137768	87402	125527	25543	76381	86788	60468	46403	82249
ACENAPHTHYLENE	0	36232	16658	13519	39249	115013	73036	30764	90663	27110	46214	50293	24598	31297
ACENAPHTHENE	8438	0	0	0	0	0	12174	0	0	0	12664	0	0	0
FLUORENE	2052	3823	1793	2467	2393	9159	4154	9833	6418	6324	6126	4088	3366	2187
PHENANTHRENE	4355	6153	5606	5710	7854	33548	16281	47607	13062	29294	16851	10749	11497	18856
ANTHRACENE	559	852	654	782	1447	4394	2614	7487	2498	4494	2327	5673	1570	2567
FLUORANTHENE	1105	1112	1760	1919	2247	7489	4528	13317	2648	8138	4163	3399	2670	4462
PYRENE	1104	1410	2336	1792	3024	8017	5074	16511	4394	7965	3326	2623	2570	4735

	RUN 1	RUN 3	RUN 2	RUN 4	RUN 6	RUN 14	RUN 5	RUN 16	RUN 9	RUN 10	RUN 7	RUN 8	RUN 12	RUN 13
BENZO(a)ANTHRACENE	485	1568	1179	637	3662	11373	3400	12011	1684	8982	4731	998	4655	6974
CHRYSENE	0	87	68	0	1899	21064	2304	2502	605	4475	1645	280	3107	3148
BENZO(e)PYRENE	0	272	386	304	1070	7099	1773	4620	6729	3664	1702	1201	2000	247
BENZO(b)FLUORANTHE	0	195	306	240	501	3150	1021	2991	4944	1675	892	632	332	1157
BENZO(k)FLUORANTHE	77	76	127	97	178	347	309	952	344	636	296	221	112	339
BENZO(a)PYRENE	177	251	389	179	476	1177	822	2459	558	1834	622	453	300	739
BENZO(g,h,i)PERYLE	0	140	228	303	299	2761	238	2759	0	997	750	503	609	559
DIBENZO(a,h)ANTHRA	0	67	107	19	63	41	878	721	0	248	174	78	285	29
INDENO(1,2,3cd)PYR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL GC/MS PAH	31056	75011	57468	57102	117003	361314	250371	279466	159501	181627	193395	144594	103484	158955
PAH CONCENTRATION (ug/m3)														
NAPHTHALENE	3781	6464	15760	8368	16351	41199	29336	42323	7137	26614	30989	21431	12674	23374
ACENAPHTHYLENE	0	10878	10477	3993	12739	34394	24514	10373	25332	9446	16501	17825	6718	8894
ACENAPHTHENE	2545	0	0	0	0	0	4086	0	0	0	4522	0	0	0
FLUORENE	619	1148	1128	729	777	2739	1394	3315	1793	2203	2187	1449	919	622
PHENANTHRENE	1313	1847	3526	1687	2549	10032	5465	16051	3650	10207	6017	3810	3140	5359
ANTHRACENE	169	256	411	231	470	1314	877	2524	698	1566	831	2011	429	730
FLUORANTHENE	333	334	1107	567	729	2240	1520	4490	740	2836	1486	1205	729	1268
PYRENE	333	423	1469	529	982	2397	1703	5567	1228	2775	1188	930	702	1346
BENZO(a)ANTHRACENE	146	471	742	188	1189	3401	1141	4050	471	3130	1689	354	1271	1982
CHRYSENE	0	26	43	0	616	6299	773	844	169	1559	587	99	849	895
BENZO(e)PYRENE	0	82	243	90	347	2123	595	1558	1880	1277	608	426	546	70
BENZO(b)FLUORANTHE	0	59	192	71	163	942	343	1008	1381	584	319	224	91	329
BENZO(k)FLUORANTHE	23	23	80	29	58	104	104	321	96	222	106	78	31	96
BENZO(a)PYRENE	53	75	245	53	155	352	276	829	156	639	222	161	82	210
BENZO(g,h,i)PERYLE	0	42	143	89	97	826	80	930	0	347	268	178	166	159
DIBENZO(a,h)ANTHRA	0	20	67	6	20	12	295	243	0	86	62	28	78	8
INDENO(1,2,3cd)PYR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL GC/MS PAH	9367	22520	36143	16866	37977	108048	84037	94226	44566	63285	69055	51247	28264	45173
PAH EMISSION RATE (mg/hr)														
NAPHTHALENE	58	91	297	144	189	438	426	857	79	320	588	400	131	313
ACENAPHTHYLENE	0	153	198	69	148	366	356	210	281	114	313	332	59	119
ACENAPHTHENE	39	0	0	0	0	0	59	0	0	0	86	0	0	0
FLUORENE	10	16	21	13	9	29	20	67	20	26	42	27	9	8
PHENANTHRENE	20	26	67	29	30	107	79	325	40	123	114	71	32	72
ANTHRACENE	3	4	8	4	5	14	13	51	8	19	16	38	4	10
FLUORANTHENE	5	5	21	10	8	24	22	91	8	34	28	22	8	17
PYRENE	5	6	28	9	11	26	25	113	14	33	23	17	7	18
BENZO(a)ANTHRACENE	2	7	14	3	14	36	17	82	5	38	32	7	13	27
CHRYSENE	0	0	1	0	7	67	11	17	2	19	11	2	9	12
BENZO(e)PYRENE	0	1	5	2	4	23	9	32	21	15	12	8	6	1
BENZO(b)FLUORANTHE	0	1	4	1	2	10	5	20	15	7	6	4	1	4
BENZO(k)FLUORANTHE	0	0	2	0	1	1	2	7	1	3	2	1	0	1
BENZO(a)PYRENE	1	1	5	1	2	4	4	17	2	8	4	3	1	3
BENZO(g,h,i)PERYLE	0	1	3	2	1	9	1	19	0	4	5	3	2	2
DIBENZO(a,h)ANTHRA	0	0	1	0	0	0	4	5	0	1	1	1	1	0
INDENO(1,2,3cd)PYR	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	RUN 1	RUN 3	RUN 2	RUN 4	RUN 6	RUN 14	RUN 5	RUN 16	RUN 9	RUN 10	RUN 7	RUN 8	RUN 12	RUN 13
TOTAL GC/MS PAH	144	316	682	291	440	1150	1221	1908	494	761	1311	956	291	605
PAH EMISSION FACTOR (mg/kg)														
NAPHTHALENE	43	71	115	69	114	263	185	294	67	196	185	127	98	161
ACENAPHTHYLENE	0	119	76	33	89	219	154	72	238	70	99	106	52	61
ACENAPHTHENE	29	0	0	0	0	0	26	0	0	0	27	0	0	0
FLUORENE	7	13	8	6	5	17	9	23	17	16	13	9	7	4
PHENANTHRENE	15	20	26	14	18	64	34	111	34	75	36	23	24	37
ANTHRACENE	2	3	3	2	3	8	6	18	7	12	5	12	3	5
FLUORANTHENE	4	4	8	5	5	14	10	31	7	21	9	7	6	9
PYRENE	4	5	11	4	7	15	11	39	12	20	7	6	5	9
BENZO(a)ANTHRACENE	2	5	5	2	8	22	7	28	4	23	10	2	10	14
CHRYSENE	0	0	0	0	4	40	5	6	2	11	4	1	7	6
BENZO(e)PYRENE	0	1	2	1	2	14	4	11	18	9	4	3	4	0
BENZO(b)FLUORANTHE	0	1	1	1	1	6	2	7	13	4	2	1	1	2
BENZO(k)FLUORANTHE	0	0	1	0	0	1	1	2	1	2	1	0	0	1
BENZO(a)PYRENE	1	1	2	0	1	2	2	6	1	5	1	1	1	1
BENZO(g,h,i)PERYLE	0	0	1	1	1	5	1	6	0	3	2	1	1	1
DIBENZO(a,h)ANTHRA	0	0	0	0	0	0	2	2	0	1	0	0	1	0
INDENO(1,2,3cd)PYR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL GC/MS PAH	107	247	263	139	265	689	529	654	418	467	412	304	219	312
ELEMENTAL ANALYSIS OF FILTERS (TABLE VALUE)														
Ag SILVER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al ALUMINUM	18	174	69	21	9	66	36	7	318	11	67	176	0	18
Ba BARIUM	17	262	85	25	0	204	43	44	491	8	118	54	0	50
Ca CALCIUM	40	246	95	70	9	123	36	17	521	12	104	48	84	38
Cd CADNIUM	0	1	0	0	0	1	1	0	0	1	0	0	2	0
Co COBALT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr CHROMIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cu COPPER	1	8	2	1	0	4	2	0	13	0	3	0	0	0
Fe IRON	4	27	8	3	0	9	5	1	32	0	5	1	2	3
K POTASSIUM	719	1061	623	545	79	413	213	102	812	108	202	120	117	121
Mg MAGNESIUM	5	58	20	7	2	16	11	2	127	0	26	11	3	0
Mn MANGANESE	2	4	2	3	0	3	1	1	10	1	1	1	7	2
Na SODIUM	172	1203	433	104	34	765	343	93	1950	83	0	295	0	89
Ni NICKEL	0	0	0	0	0	1	0	1	0	0	0	0	0	0
PO4PHOSPHOROUS	6	11	8	5	0	5	3	0	23	4	3	2	15	4
Pb LEAD	1	2	1	1	0	0	0	0	0	0	0	0	5	1
Sn TIN	2	8	0	0	0	0	4	0	8	0	1	0	0	0
Sr STRONTIUM	1	4	1	1	0	4	1	0	7	0	1	1	1	2
Ti TITANIUM	0	2	0	0	0	0	1	0	3	0	1	0	0	0
V VANADIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zn ZINC	9	188	59	17	6	199	34	25	3258	14	93	41	0	65
ELEMENTAL CONCENTRATION (ug/m3)														
Ag SILVER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al ALUMINUM	60	580	460	108	36	243	203	50	791	45	553	1391	0	85
Ba BARIUM	56	873	567	128	0	750	242	313	1221	33	973	427	0	236

	RUN 1	RUN 3	RUN 2	RUN 4	RUN 6	RUN 14	RUN 5	RUN 16	RUN 9	RUN 10	RUN 7	RUN 8	RUN 12	RUN 13
Ca CALCIUM	133	820	633	360	36	452	203	121	1296	49	858	379	245	179
Cd CADMIUM	0	3	0	0	0	4	6	0	0	4	0	0	6	0
Co COBALT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr CHROMIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cu COPPER	3	27	13	5	0	15	11	0	32	0	25	0	0	0
Fe IRON	13	90	53	15	0	33	28	7	80	0	41	8	6	14
K POTASSIUM	2385	3536	4153	2801	315	1519	1201	726	2019	440	1666	948	342	571
Mg MAGNESIUM	17	193	133	36	8	59	62	14	316	0	214	87	9	0
Mn MANGANESE	7	13	13	15	0	11	6	7	25	4	8	8	20	9
Na SODIUM	571	4009	2887	534	136	2814	1934	662	4849	338	0	2332	0	420
Ni NICKEL	0	0	0	0	0	4	0	7	0	0	0	0	0	0
PO4PHOSPHOROUS	20	37	53	26	0	18	17	0	57	16	25	16	44	19
Pb LEAD	3	7	7	5	0	0	0	0	0	0	0	0	15	5
Sn TIN	7	27	0	0	0	0	23	0	20	0	8	0	0	0
Sr STRONTIUM	3	13	7	5	0	15	6	0	17	0	8	8	3	9
Ti TITANIUM	0	7	0	0	0	0	6	0	7	0	8	0	0	0
V VANADIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zn ZINC	30	627	393	87	24	732	192	178	8102	57	767	324	0	307
ELEMENTAL EMISSION RATES (mg/hr)														
Ag SILVER	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al ALUMINUM	0.918	8.142	8.681	1.862	0.416	2.583	2.951	1.009	8.759	0.539	10.492	25.946	0.000	1.137
Ba BARIUM	0.867	12.260	10.694	2.216	0.000	7.985	3.524	6.339	13.525	0.392	18.479	7.961	0.000	3.157
Ca CALCIUM	2.039	11.512	11.952	6.205	0.416	4.815	2.951	2.449	14.351	0.588	16.286	7.076	2.530	2.399
Cd CADMIUM	0.000	0.047	0.000	0.000	0.000	0.039	0.082	0.000	0.000	0.049	0.000	0.000	0.060	0.000
Co COBALT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr CHROMIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu COPPER	0.051	0.374	0.252	0.089	0.000	0.157	0.164	0.000	0.358	0.000	0.470	0.000	0.000	0.000
Fe IRON	0.204	1.263	1.007	0.266	0.000	0.352	0.410	0.144	0.881	0.000	0.783	0.147	0.060	0.189
K POTASSIUM	36.659	49.650	78.382	48.311	3.655	16.166	17.458	14.696	22.367	5.291	31.633	17.690	3.523	7.640
Mg MAGNESIUM	0.255	2.714	2.516	0.621	0.093	0.626	0.902	0.288	3.498	0.000	4.072	1.622	0.090	0.000
Mn MANGANESE	0.102	0.187	0.252	0.266	0.000	0.117	0.082	0.144	0.275	0.049	0.157	0.147	0.211	0.126
Na SODIUM	8.770	56.295	54.477	9.219	1.573	29.945	28.113	13.399	53.714	4.066	0.000	43.488	0.000	5.619
Ni NICKEL	0.000	0.000	0.000	0.000	0.000	0.039	0.000	0.144	0.000	0.000	0.000	0.000	0.000	0.000
PO4PHOSPHOROUS	0.306	0.515	1.007	0.443	0.000	0.196	0.246	0.000	0.634	0.196	0.470	0.295	0.452	0.253
Pb LEAD	0.051	0.094	0.126	0.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.151	0.063
Sn TIN	0.102	0.374	0.000	0.000	0.000	0.000	0.328	0.000	0.220	0.000	0.157	0.000	0.000	0.000
Sr STRONTIUM	0.051	0.187	0.126	0.089	0.000	0.157	0.082	0.000	0.193	0.000	0.157	0.147	0.030	0.126
Ti TITANIUM	0.000	0.094	0.000	0.000	0.000	0.000	0.082	0.000	0.083	0.000	0.157	0.000	0.000	0.000
V VANADIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zn ZINC	0.459	8.798	7.423	1.507	0.278	7.790	2.787	3.602	89.743	0.686	14.564	6.044	0.000	4.104
ELEMENTAL EMISSION FACTOR (mg/kg)														
Ag SILVER	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al ALUMINUM	0.680	6.361	3.352	0.891	0.251	1.547	1.277	0.345	7.423	0.331	3.299	8.263	0.000	0.586
Ba BARIUM	0.642	9.578	4.129	1.060	0.000	4.782	1.526	2.171	11.462	0.240	5.811	2.535	0.000	1.627
Ca CALCIUM	1.511	8.993	4.615	2.969	0.251	2.883	1.277	0.839	12.162	0.361	5.122	2.254	1.902	1.237
Cd CADMIUM	0.000	0.037	0.000	0.000	0.000	0.023	0.035	0.000	0.000	0.030	0.000	0.000	0.045	0.000

	RUN 1	RUN 3	RUN 2	RUN 4	RUN 6	RUN 14	RUN 5	RUN 16	RUN 9	RUN 10	RUN 7	RUN 8	RUN 12	RUN 13
Co COBALT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr CHROMIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu COPPER	0.038	0.292	0.097	0.042	0.000	0.094	0.071	0.000	0.303	0.000	0.148	0.000	0.000	0.000
Fe IRON	0.151	0.987	0.389	0.127	0.000	0.211	0.177	0.049	0.747	0.000	0.246	0.047	0.045	0.098
K POTASSIUM	27.155	38.789	30.263	23.115	2.202	9.680	7.557	5.033	18.955	3.246	9.948	5.634	2.649	3.938
Mg MAGNESIUM	0.189	2.120	0.972	0.297	0.056	0.375	0.390	0.099	2.965	0.000	1.280	0.516	0.068	0.000
Mn MANGANESE	0.076	0.146	0.097	0.127	0.000	0.070	0.035	0.049	0.233	0.030	0.049	0.047	0.159	0.065
Na SODIUM	6.496	43.980	21.034	4.411	0.948	17.931	12.170	4.589	45.520	2.495	0.000	13.850	0.000	2.897
Ni NICKEL	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.049	0.000	0.000	0.000	0.000	0.000	0.000
PO4PHOSPHOROUS	0.227	0.402	0.389	0.212	0.000	0.117	0.106	0.000	0.537	0.120	0.148	0.094	0.340	0.130
Pb LEAD	0.038	0.073	0.049	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.113	0.033
Sn TIN	0.076	0.292	0.000	0.000	0.000	0.000	0.142	0.000	0.187	0.000	0.049	0.000	0.000	0.000
Sr STRONTIUM	0.038	0.146	0.049	0.042	0.000	0.094	0.035	0.000	0.163	0.000	0.049	0.047	0.023	0.065
Ti TITANIUM	0.000	0.073	0.000	0.000	0.000	0.000	0.035	0.000	0.070	0.000	0.049	0.000	0.000	0.000
V VANADIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zn ZINC	0.340	6.873	2.866	0.721	0.167	4.664	1.206	1.234	76.054	0.421	4.580	1.925	0.000	2.115

C1-C7 HYDROCARBONS (ppbC)	Run 1	Run 3	Run 2	RUN 4	RUN 6	Run 14	Run 5	Run 16	RUN 9	Run 10	Run 7	Run 8	Run 12	Run 13
METHANE	0	36900	28800	16000	30500	103000	27000	29200	171000	38100	53300	42600	96100	53800
ETHANE	7941	11638	9156	3518	2305	19178	7031	5843	29424	5096	5306	4561	13887	5108
ETHYLENE	21314	28892	35728	24344	12981	57084	41739	32740	48495	35679	18752	30902	22458	30574
ACETYLENE	5026	5786	9647	5678	3136	13619	10831	13177	7783	11292	13358	10418	4296	4918
PROPANE	1910	3111	1954	617	533	5085	1383	739	9117	941	826	720	1386	858
PROPENE	6229	8730	8065	3223	2781	18289	9398	7746	21220	7805	6336	5119	5419	5687
I-BUTANE	182	218	164	68	42	324	109	63	715	63	70	66	76	63
N-BUTANE	365	520	321	85	83	613	491	90	1412	112	107	87	129	76
BUTENES	6455	9281	9104	0	5087	16023	10176	8493	18521	7351	5753	4392	6070	4648
PENTENES	5148	7505	5721	0	1397	5695	2266	1388	11657	2553	2484	2096	1195	1062
C6 HYDROCARBONS	2028	5896	3306	0	1223	7089	2652	2255	6118	1718	1500	1127	1373	821
BENZENE	6613	10474	13791	0	11723	29559	25827	24168	16696	18722	19593	14593	11147	12772
TOLUENE	2202	3907	3340	0	3413	13485	7870	8638	11291	6298	4919	3927	4069	4307
FURAN	1169	1826	2008	0	1524	3680	3258	3025	2555	2247	2102	1762	770	765
METHYL ETHYL KETONE	1413	2564	1826	0	452	3226	1104	621	5001	506	526	431	448	273
2-METHYL FURAN	5255	9040	5294	0	941	4868	1421	787	11617	658	637	535	628	445
2,5-DIMETHYL FURAN	1324	2386	1249	0	191	1362	349	248	2867	182	159	123	164	116
FURFURAL	2809	6228	2737	0	605	4981	965	1534	4973	997	493	598	1068	510
O-XYLENE	514	903	1037	0	1019	4652	2416	3653	2321	2579	0	0	1473	1523
TOTAL NMHC	91525	141586	132577	37532	57139	237616	144379	127343	248076	116421	92659	89073	84695	81056
TOTAL HC	91525	178486	161377	53532	87639	340616	171379	156543	419076	154521	145959	131673	180795	134856

C1-C7 HYDROCARBONS (ug/m3)	Run 1	Run 3	Run 2	RUN 4	RUN 6	Run 14	Run 5	Run 16	RUN 9	Run 10	Run 7	Run 8	Run 12	Run 13
METHANE	0	391055	308423	167172	309034	1088254	263004	309357	1751448	398128	533795	430322	981333	562432
ETHANE	75066	115609	91907	34457	21888	189927	64196	58021	282487	49910	49812	43188	132926	50056
ETHYLENE	187933	267726	334554	222397	115001	527356	355503	303290	434309	325990	164211	272943	200519	279472
ACETYLENE	41141	49769	83860	48152	25792	116797	85641	113322	64706	95781	108594	85425	35612	41734
PROPANE	17652	30212	19174	5909	4948	49237	12342	7176	85581	9012	7578	6663	12970	8221
PROPENE	54932	80906	75525	29445	24638	168976	80051	71759	190058	71318	55486	45221	48393	51988
I-BUTANE	1665	2094	1588	639	385	3103	962	605	6632	597	635	602	705	598
N-BUTANE	3331	4990	3110	808	759	5870	4328	864	13104	1061	966	792	1192	717
BUTENES	56926	86019	85261	0	45078	148050	86687	78691	165901	67179	50389	38796	54211	42494
PENTENES	45393	69545	53577	0	12377	52617	19299	12855	104400	23329	21751	18518	10672	9708
C6 HYDROCARBONS	18312	55950	31701	0	11092	67066	23133	21393	56110	16072	13456	10196	12559	7681
BENZENE	54124	90093	119871	0	96404	253474	204188	207808	138793	158778	159259	119643	92383	108370
TOLUENE	18224	33979	29352	0	28380	116923	62907	75102	94899	54010	40428	32555	34097	36948
FURAN	12504	20526	22817	0	16384	41253	33674	34005	27759	24913	22335	18886	8338	8488
METHYL ETHYL KETONE	16017	30539	21973	0	5142	38313	12081	7393	57573	5945	5921	4888	5144	3211
2-METHYL FURAN	54250	98073	58040	0	9755	52646	14174	8531	121804	7043	6526	5534	6565	4758
2,5-DIMETHYL FURAN	13332	25260	13356	0	1930	14369	3394	2622	29328	1900	1594	1243	1668	1212
FURFURAL	33933	79082	35116	0	7341	63052	11262	19474	61027	12481	5913	7241	13063	6385
O-XYLENE	4284	7918	9186	0	8541	40663	19469	32017	19667	22299	0	0	12448	13172
TOTAL NMHC	709019	1148291	1089967	341807	435835	1949691	1093291	1054928	1954137	947618	714855	712332	683463	675215
TOTAL HC	709019	1539346	1398390	508979	744869	3037945	1356295	1364285	3705585	1345745	1248649	1142654	1664796	1237647

	Run 1	Run 3	Run 2	RUN 4	RUN 6	Run 14	Run 5	Run 16	RUN 9	Run 10	Run 7	Run 8	Run 12	Run 13
C1-C7 HYDROCARBONS (mg/hr)														
METHANE	0	5491	5821	2883	3581	11581	3823	6265	19401	4785	10135	8026	10113	7528
ETHANE	1154	1623	1734	594	254	2021	933	1175	3129	600	946	806	1370	670
ETHYLENE	2888	3759	6314	3836	1333	5612	5167	6142	4811	3918	3118	5091	2066	3740
ACETYLENE	632	699	1583	831	299	1243	1245	2295	717	1151	2062	1593	367	559
PROPANE	271	424	362	102	57	524	179	145	948	108	144	124	134	110
PROPENE	844	1136	1425	508	286	1798	1164	1453	2105	857	1053	843	499	696
I-BUTANE	26	29	30	11	4	33	14	12	73	7	12	11	7	8
N-BUTANE	51	70	59	14	9	62	63	17	145	13	18	15	12	10
BUTENES	875	1208	1609	0	522	1576	1260	1594	1838	807	957	724	559	569
PENTENES	698	977	1011	0	143	560	281	260	1156	280	413	345	110	130
C6 HYDROCARBONS	281	786	598	0	129	714	336	433	622	193	255	190	129	103
BENZENE	832	1265	2262	0	1117	2697	2968	4209	1537	1908	3024	2232	952	1450
TOLUENE	280	477	554	0	329	1244	914	1521	1051	649	768	607	351	495
FURAN	192	288	431	0	190	439	489	689	307	299	424	352	86	114
METHYL ETHYL KETONE	246	429	415	0	60	408	176	150	638	71	112	91	53	43
2-METHYL FURAN	834	1377	1095	0	113	560	206	173	1349	85	124	103	68	64
2,5-DIMETHYL FURAN	205	355	252	0	22	153	49	53	325	23	30	23	17	16
FURFURAL	521	1110	663	0	85	671	164	394	676	150	112	135	135	85
O-XYLENE	66	111	173	0	99	433	283	648	218	268	0	0	128	176
TOTAL NMHC	10896	16124	20570	5895	5051	20749	15891	21364	21646	11388	13572	13286	7043	9037
TOTAL HC	10896	21615	26390	8779	8632	32330	19714	27629	41047	16173	23707	21313	17156	16565
CI-C7 HYDROCARBONS(mg/kg)														
METHANE	0	4290	2247	1380	2157	6935	1655	2146	16441	2935	3187	2556	7603	3880
ETHANE	855	1268	670	284	153	1210	404	402	2652	368	297	257	1030	345
ETHYLENE	2139	2937	2438	1835	803	3361	2237	2104	4077	2404	980	1621	1554	1928
ACETYLENE	468	546	611	397	180	744	539	786	607	706	648	507	276	288
PROPANE	201	331	140	49	35	314	78	50	803	66	45	40	100	57
PROPENE	625	888	550	243	172	1077	504	498	1784	526	331	269	375	359
I-BUTANE	19	23	12	5	3	20	6	4	62	4	4	4	5	4
N-BUTANE	38	55	23	7	5	37	27	6	123	8	6	5	9	5
BUTENES	648	944	621	0	315	943	545	546	1557	495	301	230	420	293
PENTENES	517	763	390	0	86	335	121	89	980	172	130	110	83	67
C6 HYDROCARBONS	208	614	231	0	77	427	146	148	527	118	80	61	97	53
BENZENE	616	988	873	0	673	1615	1285	1441	1303	1171	951	711	716	748
TOLUENE	207	373	214	0	198	745	396	521	891	398	241	193	264	255
FURAN	142	225	166	0	114	263	212	236	261	184	133	112	65	59
METHYL ETHYL KETONE	182	335	160	0	36	244	76	51	540	44	35	29	40	22
2-METHYL FURAN	618	1076	423	0	68	335	89	59	1143	52	39	33	51	33
2,5-DIMETHYL FURAN	152	277	97	0	13	92	21	18	275	14	10	7	13	8
FURFURAL	386	868	256	0	51	402	71	135	573	92	35	43	101	44
O-XYLENE	49	87	67	0	60	259	123	222	185	164	0	0	96	91
TOTAL NMHC	8071	12597	7942	2821	3043	12424	6879	7317	18344	6987	4268	4231	5296	4658
TOTAL HC	8071	16887	10189	4200	5200	19359	8534	9462	34785	9922	7455	6788	12899	8538
CO (g/m3)	11	14	18	15	20	21	23	19	22	19	26	29	6	11
CO (g/hr)	167	190	341	251	235	221	337	387	243	230	484	539	59	150
CO (g/kg)	123	148	132	120	142	132	146	133	206	141	152	172	44	77

APPENDIX B. STATISTICAL METHODOLOGY

(Revision)

Memo to: R. McCrillis
From: Ross Leadbetter
Subject: Statistical analysis of woodstove data
Date: May 5, 1988

I enclose the statistical analysis (by Dr. N. L. Johnson) of the particulate emissions data (in g/hr) which you requested. In view of some "lack of balance" in the experimental design, it has been convenient to analyze the data in two parts. In the first of these fuel and altitude effects are studied for one stove, and in the second, the two stoves are compared. The general conclusion is that fuel and stove differences are large enough to suggest that they may be real, though not statistically significant due to the large variability between replicate measurements. We have described this is detail in the attached analysis.

Analysis of stove experiment data - Particulate emissions (g/hr)

The following analysis applies directly to particulate emissions, but the principles apply generally. In this the factors are denoted by

A = fuel   B = stove   C = altitude   D = burn rate

In this A can take the levels a_0("lower"), a_1("upper") and similarly for B, C, D.

Note that if run 5 had not been aborted the data would represent

(i) two replicates of a 3/4 fraction of a 2^3 experiment, with B at upper level (b_1) (excluding factor level combinations $a_1c_0d_1$ and $a_1c_0d_0$), plus

(ii) two single replicates with B at lower level (b_0) and factor level conbinations $a_0c_0d_0$, $a_0c_0d_1$.

The experiment (i) is analyzed first. Since only one stove is used for this the comparisons apply only to that stove. The data in (ii) is then augmented by part of that in (i) to compare stoves, at the lower levels of A and C only.

Analysis for (i):

Tests were not run for the combinations $a_1c_0d_0$ or $a_1c_0d_1$. The means for these are labeled x, y respectively and are "filled in" by assuming that ACD and AC interactions are both zero. For simplicity it is assumed that the one value given for $a_0c_1d_1$ is the mean of two measurements (that given, and the missing value). This leads to the following data table.

	Values	Difference	Mean
$a_0c_0d_0$	50.666, 11.153	39.513	30.909
$a_1c_0d_0$	-	-	x
$a_0c_1d_0$	10.905, 30,713	-19.808	20.809
$a_1c_1d_0$	31.535, 34.698	- 3.163	33.116
$a_0c_0d_1$	12.873, 11.340	1.533	12.106
$a_1c_0d_1$	-	-	y
$a_0c_1d_1$	22.540 -	-	22.540
$a_1c_1d_1$	43.575, 15.851	27.724	29.713

This gives the following "Yates Table"

30.909 + x	84.834 + x	149.193 + x+y	Total
53.925	64.359 + y	-23.535 + x+y	A
12.106 + y	x - 18.602	63.163 - x-y	C
52.253	y - 4.933	62.495 - x-y	AC
x - 30.909	23.016 - x	-20.475 - x+y	D
12.307	40.147 - y	13.669 - x+y	AD
y - 12.106	43.216 - x	17.131 + x-y	CD
7.173	19.279 - y	-23.937 + x-y	ACD

Assuming the interactions AC and ACD and zero we have $x - y = +23.937$, $x + y = 62.495$. This gives the following values for the second last column in the Yates table, viz.

Total	211.588
A	38.960
C	0.668
AC	0
D	-44.412
AD	-10.268
CD	41.068
ACD	0

The actual main effects and interaction estimates are obtained by dividing each value by 4, giving

Main effects and interaction (g/hr):

A (Fuel)	C (Altitude)	AC	D (Rate)	AD	CD	ACD
9.74	.17	0	-11.10	-2.57	10.27	0

The estimated error variance is

$$\hat{\sigma}^2 = \frac{1}{10}\{(-3.163)^2 + (27.724)^2 + (-19.808)^2 + (39.513)^2 + (1.533)^2\}$$

$$= 273.461 \quad (\text{s.d. } \hat{\sigma} = 16.54)$$

The estimated variance for each "mean" in the data table is thus $\frac{1}{2}\hat{\sigma}^2 = 136.73$ (s.d. = 11.69) except for the $a_0c_1d_1$ value for which the variance is 273.461 (s.d. = 16.54).

If there were no missing factor level combinations, the estimated variance of each of the estimators in the Yates Table would be $\frac{1}{2}\hat{\sigma}^2 \times 8 = 4\hat{\sigma}^2$ but due to the missing combinations it is $\frac{1}{2}\hat{\sigma}^2 \times 16 = 8\hat{\sigma}^2$. The variance for the actual estimated main effects and interactions is thus $8\hat{\sigma}^2/16 = \hat{\sigma}^2/2 =$ 136.73, with s.d. 11.7.

For 5% (one-sided) statistical significance (allowing five degrees of freedom for error) a main effect or interaction should exceed 2.015 × 11.7 = 23.6. (None does.)

Conclusions for (i):

None of the main effects or interactions appear significant (since none exceed 23.6), but the main effects of fuel (A) and rate D and their interaction (AD) are quite possibly real. The large variability between replicates and omission of two-factor level combinations causes this "insensitivity" in drawing conclusions.

Analysis for (ii):

By combining the data in runs (12) and (13) with that in (9) and (10) and (7) and (8), we have a complete single replicate 2^2 experiment with factors B (stove) and D (rate) at the fixed lower levels of A (fuel) and B (altitude). This gives the following Yates Table:

b_0d_0	6.193	37.102	57.252	Total
b_1d_0	30.909	20.150	28.778	B
b_0d_1	8.044	24.716	-16.952	D
b_1d_1	12.106	4.062	-20.654	BD

The estimates of main effects B, D and interaction BD are obtained by dividing these by 2, giving the following values:

Main effects and interaction:

B (Stove)	D (Burn rate)	BD
14.39	-8.48	-10.33

The estimated variance of each term is similarly calculated to be $(2\times(\frac{1}{2}\hat{\sigma}^2) + 2\hat{\sigma}^2)/4 = 205.10$, with s.d. = 14.32 For 5% (one-sided) significance the (absolute) value should exceed 2.015 ×14.32 = 28.86. Again none of the entries exceed 28.86 though the B and BD estimates are of moderate size.

Conclusions for (ii): Neither stove effect (B) nor burn rate effect (D) is significant, though that for stove seems as if it may be real. The stove-burn rate interaction may also be large enough to be of interest, even though non-significant by this test. Again the large variability between replicates could be masking actual differences.

General Conclusion:

The analysis gives somewhat disappointing results, mainly due to the points mentioned above - large variability between replicates and (to a lesser extent) the omission of the $a_1c_0d_0$ and $a_1c_0d_1$ factor level combinations. More accurate (or more extensive) experimentation might well give significant results for the main effects B and A, showing real differences between stoves and between fuel types. The interactions BD and CD may also be real.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
RESEARCH TRIANGLE PARK
NORTH CAROLINA 27711

July 28, 1988

Mr. Paul Burnet
OMNI Environmental Services, Inc.,
10950 SW 5th Street, Suite 160
Beaverton, OR 97005

Dear Paul:

Ross Leadbetter has discussed the problem of negative estimated values on the IACP woodstove study with Norman Johnson, also at UNC. The following is their recommendation for handling those cases where either or both x and y are calculated to have negative values by the current model. If both x and y are estimated by the model to have positive values, then they should be used. In other words, if $x > 0$ and $y > 0$, the current model works satisfactorily.

Ross used the following simple examples to illustrate their recommended approach.

First case: $x = 1.1$ $y = -1.5$ as calculated by the current model

The 3-factor interaction ACD in the last column of the Yates Table includes the $x - y$ term. The assumption that ACD = 0 is retained. In this case set

$$x - y = 2.6$$

and

$$y = 0$$

thus

$$x = 2.6$$

and

$$x + y = 2.6$$

Second case: $x = -1.1$ $y = 1.5$ as calculated by the current model.

The ACD interaction is again assumed to be zero. In this case, set

$$x - y = -2.6$$

and

$$x = 0$$

Thus

$$y = 2.6$$

and

$$x + y = 2.6$$

Third case: $x = -1.1$ $y = -1.5$ as calculated by the current model.

The ACD interaction is again assumed to be zero as before. In this case set

$$x - y = 0.4$$

and

$$y = 0$$

Thus

$$x = 0.4$$

and

$$x + y = 0.4$$

In all instances where the current model gave results illustrated by the above three cases you need to go back and recalculate the Yates Table with the new assumptions. The general concept behind Ross' recommendation is to maintain the three factor ACD interaction at zero but allow all the two factor interactions, including AC, to be non-zero. The new assumed values of x and y will eliminate any negative estimated values. There will obviously be instances where one of the estimated values is zero. I think this can be explained by noting that these are only estimated values and the fact that sometimes they are zero reflects the wide variability in the measured values. You will have to be sure to highlight the fact that throughout the report the values shown for the $a_1c_0d_0$ and $a_1c_0d_1$ test conditions are only estimates generated to enable statistical analysis of the data.

Enclosed is a copy of the pages from the draft report with my comments noted in the margins. As we discussed, I think it would be interesting to look at the 90, 95, and 99% confidence intervals (or bounds). I realize funds are short, however.

Please call if you have any questions.

Sincerely yours,

Robert C. McCrillis
Air Toxics Control Branch
Air Toxics Research Division (MD-61)

APPENDIX C. ANOVA MAIN EFFECT DATA PRINTOUTS -- 99% CONFIDENCE BOUND

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Results from IACP Boise source lab study


                  "YATES" table for fuel, altitude and burnrate for         "YATES" table for stove and rate for
                  BURN RATE (kg/hr)                                          BURN RATE (kg/hr)

FIRST   SECOND  DIFFERENCE  MEAN                                              MEAN
VALUE   VALUE               VALUE    1      2      3                          VALUE     1        2

  1.2     1.6     -0.4       1.4    2.5    5.4   16.4   Total                   1.3    2.7       7.8  Total
  1.1     1.1      0.0       1.1    3.0   11.0   -1.3   A                       1.4    5.1       1.3  B
  1.7     1.7     -0.0       1.7    6.0   -0.7   -0.6   C                       1.9    0.1       2.4  D
  1.4     1.3      0.1       1.3    5.0   -0.6    0.0   AC                      3.2    1.2       1.1  BD
  3.2     3.1      0.0       3.2   -0.4    0.5    5.6   D
  2.9     2.9      0.0       2.9   -0.4   -1.1    0.1   AD
  2.9     2.3      0.6       2.6   -0.3    0.0   -1.6   CD
  2.6     2.1      0.5       2.3   -0.3    0.0   -0.0   ACD


                        A        AC      C        D       AD      CD                            B         D        BD
                       Fuel            Altitude  Rate                                         Stove      Rate
Main Effects           -0.3      0.0    -0.1      1.4     0.0    -0.4     Main Effects          0.6       1.2       0.6
Error Variance          0.0                                               Error Variance        0.0
Variance of Mean        0.0                                               Variance of Mean      0.0
Stand. Deviation        0.2                                               Stand. Deviation      0.2
(Signif. if > +-1)
@90%CB,                -1.4      0.0    -0.6      6.2     0.2    -1.8     Signif. if > +-1      2.0       3.7       1.8
@95%CB,                -1.0      0.0    -0.5      4.6     0.1    -1.3     Signif. if > +-1      1.5       2.7       1.3
@99%CB,                -0.6      0.0    -0.3      2.7     0.1    -0.8     Signif. if > +-1      0.9       1.6       0.8
```

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
TOTAL FUEL BURNED (KG)

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
8.9	11.7	-2.8	10.3	19.4	42.7	116.1	Total
9.1	9.1	0.0	9.1	23.4	73.4	-12.4	A
12.3	12.3	0.0	12.3	40.5	-2.5	-3.5	C
11.0	11.1	-0.1	11.1	33.0	-9.9	0.0	AC
23.1	22.3	0.8	22.7	-1.3	4.0	30.7	D
17.8	17.8	0.0	17.8	-1.3	-7.5	-7.4	AD
21.1	16.8	4.3	19.0	-5.0	0.0	-11.5	CD
10.6	17.4	-6.8	14.0	-5.0	0.0	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-3.1	0.0	-0.9	7.7	-1.9	-2.9
Error Variance	5.5					
Variance of Mean	2.7					
Stand. Deviation	1.7					
(Signif. if > +-1)						
@90%CB,	-1.3	0.0	-0.4	3.1	-0.8	-1.2
@95%CB,	-0.9	0.0	-0.3	2.3	-0.6	-0.9
@99%CB,	-0.6	0.0	-0.2	1.4	-0.3	-0.5

"YATES" table for stove and rate for
TOTAL FUEL BURNED (KG)

MEAN VALUE	1	2	
10.7	21.0	60.3	Total
10.3	39.3	5.7	B
16.6	-0.4	18.3	D
22.7	6.1	6.5	BD

	B Stove	D Rate	BD
Main Effects	2.9	9.2	3.3
Error Variance	5.5		
Variance of Mean	4.1		
Stand. Deviation	2.3		
Signif. if > +-1	0.8	2.6	0.9
Signif. if > +-1	0.6	1.9	0.7
Signif. if > +-1	0.4	1.2	0.4

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
STACK FLOW (m3/hr)

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
11.1	12.0	-0.9	11.5	26.7	52.5	126.3	Total
15.1	15.1	0.0	15.1	25.8	73.8	8.5	A
11.6	10.6	0.9	11.1	38.3	7.2	-3.7	C
15.4	14.0	1.3	14.7	35.5	1.3	0.0	AC
19.0	18.7	0.3	18.8	3.6	-0.9	21.3	D
19.5	19.5	0.0	19.5	3.6	-2.9	-5.8	AD
20.3	14.5	5.7	17.4	0.7	0.0	-2.0	CD
18.9	17.2	1.6	18.1	0.7	0.0	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	2.1	0.0	-0.9	5.3	-1.5	-0.5
Error Variance	0.6					
Variance of Mean	0.3					
Stand. Deviation	0.6					
(Signif. if > +-1)						
@90%CB,	2.6	0.0	-1.1	6.4	-1.8	-0.6
@95%CB,	1.9	0.0	-0.8	4.7	-1.3	-0.4
@99%CB,	1.1	0.0	-0.5	2.8	-0.8	-0.3

"YATES" table for stove and rate for
STACK FLOW (m3/hr)

MEAN VALUE	1	2	
10.3	21.9	54.1	Total
11.5	32.2	6.7	B
13.4	1.2	10.4	D
18.8	5.4	4.2	BD

	B Stove	D Rate	BD
Main Effects	3.3	5.2	2.1
Error Variance	0.6		
Variance of Mean	0.5		
Stand. Deviation	0.8		
Signif. if > +-1	2.9	4.4	1.8
Signif. if > +-1	2.1	3.2	1.3
Signif. if > +-1	1.3	1.9	0.8

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
STACK TEMPERATURE (C)

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
90.0	119.0	-29.0	104.5	194.0	469.0	1237.0	Total
89.5	89.5	0.0	89.5	275.0	768.0	16.0	A
171.0	119.0	52.0	145.0	422.0	-30.0	5.0	C
142.0	118.0	24.0	130.0	346.0	46.0	0.0	AC
204.0	195.0	9.0	199.5	-15.0	81.0	299.0	D
222.5	222.5	0.0	222.5	-15.0	-76.0	76.0	AD
195.0	128.0	67.0	161.5	23.0	0.0	-157.0	CD
211.0	158.0	53.0	184.5	23.0	0.0	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	4.0	0.0	1.3	74.8	19.0	-39.3
Error Variance	701.1					
Variance of Mean	350.6					
Stand. Deviation	18.7					
(Signif. if > +-1)						
@90%CB,	0.1	0.0	0.0	2.7	0.7	-1.4
@95%CB,	0.1	0.0	0.0	2.0	0.5	-1.0
@99%CB,	0.1	0.0	0.0	1.2	0.3	-0.6

"YATES" table for stove and rate for
STACK TEMPERATURE (C)

MEAN VALUE	1	2	
103.0	207.5	536.0	Total
104.5	328.5	72.0	B
129.0	1.5	121.0	D
199.5	70.5	69.0	BD

	B Stove	D Rate	BD
Main Effects	36.0	60.5	34.5
Error Variance	701.1		
Variance of Mean	525.8		
Stand. Deviation	26.5		
Signif. if > +-1	0.9	1.5	0.9
Signif. if > +-1	0.7	1.1	0.6
Signif. if > +-1	0.4	0.7	0.4

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for CO AVERAGE (%)

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
1.9	1.6	0.2	1.8	2.8	5.6	13.1	Total
1.0	1.0	0.0	1.0	2.8	7.5	-2.3	A
1.7	1.8	-0.0	1.8	4.3	-1.4	-1.0	C
0.9	1.2	-0.2	1.0	3.2	-0.8	0.0	AC
2.2	2.5	-0.3	2.3	-0.7	0.0	1.9	D
1.9	1.9	0.0	1.9	-0.7	-1.0	0.6	AD
1.6	2.0	-0.4	1.8	-0.4	-0.0	-1.0	CD
1.6	1.3	0.3	1.4	-0.4	0.0	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-0.6	0.0	-0.3	0.5	0.1	-0.3
Error Variance	0.0					
Variance of Mean	0.0					
Stand. Deviation	0.1					
(Signif. if > +-1)						
@90%CB,	-3.2	0.0	-1.5	2.6	0.8	-1.5
@95%CB,	-2.3	0.0	-1.1	1.9	0.6	-1.1
@99%CB,	-1.4	0.0	-0.6	1.2	0.4	-0.6

"YATES" table for stove and rate for CO AVERAGE (%)

MEAN VALUE	1	2	
0.5	2.3	5.5	Total
1.8	3.3	2.6	B
1.0	1.3	1.0	D
2.3	1.4	0.1	BD

	B Stove	D Rate	BD
Main Effects	1.3	0.5	0.1
Error Variance	0.0		
Variance of Mean	0.0		
Stand. Deviation	0.2		
Signif. if > +-1	5.3	2.1	0.2
Signif. if > +-1	3.9	1.5	0.2
Signif. if > +-1	2.3	0.9	0.1

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
CO2 AVERAGE(%)

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
8.0	11.3	-3.3	9.7	13.2	32.4	80.7	Total
3.5	3.5	0.0	3.5	19.3	48.3	-17.6	A
12.0	13.4	-1.4	12.7	25.4	-12.3	3.7	C
6.5	6.6	-0.1	6.5	23.0	-5.3	-0.0	AC
14.1	13.9	0.2	14.0	-6.2	6.1	15.9	D
11.4	11.4	0.0	11.4	-6.1	-2.4	7.0	AD
12.2	13.4	-1.2	12.8	-2.6	0.0	-8.5	CD
10.8	9.5	1.3	10.2	-2.7	-0.0	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-4.4	-0.0	0.9	4.0	1.8	-2.1
Error Variance	1.5					
Variance of Mean	0.7					
Stand. Deviation	0.9					
(Signif. if > +-1)						
@90%CB,	-3.5	-0.0	0.7	3.2	1.4	-1.7
@95%CB,	-2.6	-0.0	0.5	2.3	1.0	-1.2
@99%CB,	-1.5	-0.0	0.3	1.4	0.6	-0.7

"YATES" table for stove and rate for
CO2 AVERAGE(%)

MEAN VALUE	1	2	
12.2	21.9	49.3	Total
9.7	27.4	-1.9	B
13.4	-2.5	5.5	D
14.0	0.6	3.1	BD

	B Stove	D Rate	BD
Main Effects	-1.0	2.8	1.6
Error Variance	1.5		
Variance of Mean	1.1		
Stand. Deviation	1.2		
Signif. if > +-1	-0.5	1.6	0.9
Signif. if > +-1	-0.4	1.1	0.6
Signif. if > +-1	-0.2	0.7	0.4

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
O2 AVERAGE (%)

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
11.8	8.7	3.1	10.3	26.2	47.8	81.1	Total
15.9	15.9	0.0	15.9	21.6	33.3	17.9	A
8.0	7.9	0.1	8.0	15.9	11.4	-3.2	C
13.9	13.4	0.5	13.7	17.4	6.5	0.0	AC
6.2	6.5	-0.3	6.3	5.7	-4.6	-14.5	D
9.6	9.6	0.0	9.6	5.7	1.4	-4.9	AD
7.3	6.8	0.5	7.0	3.3	0.0	6.0	CD
9.6	11.0	-1.4	10.3	3.3	0.0	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	4.5	0.0	-0.8	-3.6	-1.2	1.5
Error Variance	1.2					
Variance of Mean	0.6					
Stand. Deviation	0.8					
(Signif. if > +-1)						
@90%CB,	3.9	0.0	-0.7	-3.2	-1.1	1.3
@95%CB,	2.9	0.0	-0.5	-2.3	-0.8	1.0
@99%CB,	1.7	0.0	-0.3	-1.4	-0.5	0.6

"YATES" table for stove and rate for
O2 AVERAGE (%)

MEAN VALUE	1	2	
8.0	18.3	31.9	Total
10.3	13.6	1.3	B
7.3	2.3	-4.6	D
6.3	-1.0	-3.2	BD

	B Stove	D Rate	BD
Main Effects	0.6	-2.3	-1.6
Error Variance	1.2		
Variance of Mean	0.9		
Stand. Deviation	1.1		
Signif. if > +-1	0.4	-1.4	-1.0
Signif. if > +-1	0.3	-1.0	-0.7
Signif. if > +-1	0.2	-0.6	-0.4

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for PYRENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
1227.7	2775.3	-1547.5	2001.5	6200.7	8268.3	15893.2	Total
4199.2	4199.2	0.0	4199.2	2067.6	7624.8	-4739.9	A
981.5	2397.4	-1415.9	1689.5	1058.6	886.4	1374.5	C
333.0	423.3	-90.4	378.1	6566.2	-5626.3	-7018.2	AC
1187.6	929.6	258.0	1058.6	2197.7	-4133.1	-643.5	D
0.0	0.0	0.0	0.0	-1311.3	5507.6	-6512.7	AD
5566.9	5566.9	0.0	5566.9	-1058.6	-3509.1	9640.7	CD
1469.2	529.3	939.9	999.2	-4567.7	-3509.1	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-1185.0	-1754.5	343.6	-160.9	-1628.2	2410.2
Error Variance	535773.9					
Variance of Mean	267886.9					
Stand. Deviation	517.6					
(Signif. if > +-1)						
@90%CB,	-1.6	-2.3	0.4	-0.2	-2.1	3.2
@95%CB,	-1.1	-1.7	0.3	-0.2	-1.6	2.3
@99%CB,	-0.7	-1.0	0.2	-0.1	-0.9	1.4

"YATES" table for stove and rate for PYRENE

MEAN VALUE	1	2	
701.9	2703.4	5107.7	Total
2001.5	2404.3	1012.6	B
1345.6	1299.6	-299.2	D
1058.6	-287.0	-1586.6	BD

	B Stove	D Rate	BD
Main Effects	506.3	-149.6	-793.3
Error Variance	535773.9		
Variance of Mean	401830.4		
Stand. Deviation	732.0		
Signif. if > +-1	0.5	-0.1	-0.7
Signif. if > +-1	0.3	-0.1	-0.5
Signif. if > +-1	0.2	-0.1	-0.3

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for BENZO(k)FLUORANTHE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
96.1	221.6	-125.5	158.9	434.7	538.5	1005.7	Total
275.8	275.8	0.0	275.8	103.8	467.3	-299.5	A
57.8	103.8	-46.0	80.8	92.0	59.2	-47.7	C
23.2	22.8	0.4	23.0	375.2	-358.7	-349.4	AC
105.7	78.3	27.4	92.0	117.0	-330.9	-71.2	D
0.0	0.0	0.0	0.0	-57.8	283.2	-417.9	AD
321.0	321.0	0.0	321.0	-92.0	-174.7	614.1	CD
79.9	28.7	51.2	54.3	-266.7	-174.7	0.0	ACD

	A	AC	C	D	AD	CD
	Fuel		Altitude	Rate		
Main Effects	-74.9	-87.4	-11.9	-17.8	-104.5	153.5
Error Variance	2123.5					
Variance of Mean	1061.8					
Stand. Deviation	32.6					
(Signif. if > +-1)						
@90%CB,	-1.6	-1.8	-0.2	-0.4	-2.2	3.2
@95%CB,	-1.1	-1.3	-0.2	-0.3	-1.6	2.3
@99%CB,	-0.7	-0.8	-0.1	-0.2	-1.0	1.4

"YATES" table for stove and rate for BENZO(k)FLUORANTHE

MEAN VALUE	1	2	
30.6	189.4	377.8	Total
158.9	188.3	123.9	B
96.3	128.3	-1.1	D
92.0	-4.3	-132.6	BD

	B	D	BD
	Stove	Rate	
Main Effects	62.0	-0.5	-66.3
Error Variance	2123.5		
Variance of Mean	1592.6		
Stand. Deviation	46.1		
Signif. if > +-1	0.9	-0.0	-1.0
Signif. if > +-1	0.7	-0.0	-0.7
Signif. if > +-1	0.4	-0.0	-0.4

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for DIBENZO(a,h)ANTHRA

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	86.4	-86.4	43.2	241.9	268.3	592.7	Total
198.7	198.7	0.0	198.7	26.4	324.4	-102.4	A
20.4	12.3	8.2	16.4	44.9	149.2	19.2	C
0.0	20.1	-20.1	10.1	279.6	-251.5	-323.5	AC
62.1	27.6	34.5	44.9	155.5	-215.5	56.2	D
0.0	0.0	0.0	0.0	-6.3	234.7	-400.7	AD
243.1	243.1	0.0	243.1	-44.9	-161.8	450.1	CD
67.3	5.6	61.7	36.5	-206.6	-161.8	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-25.6	-80.9	4.8	14.0	-100.2	112.5
Error Variance	1293.3					
Variance of Mean	646.6					
Stand. Deviation	25.4					
(Signif. if > +-1)						
@90%CB,	-0.7	-2.2	0.1	0.4	-2.7	3.0
@95%CB,	-0.5	-1.6	0.1	0.3	-2.0	2.2
@99%CB,	-0.3	-0.9	0.1	0.2	-1.2	1.3

"YATES" table for stove and rate for DIBENZO(a,h)ANTHRA

MEAN VALUE	1	2	
77.8	121.0	174.2	Total
43.2	53.1	2.0	B
8.2	-34.6	-67.9	D
44.9	36.6	71.3	BD

	B Stove	D Rate	BD
Main Effects	1.0	-34.0	35.6
Error Variance	1293.3		
Variance of Mean	969.9		
Stand. Deviation	36.0		
Signif. if > +-1	0.0	-0.6	0.7
Signif. if > +-1	0.0	-0.5	0.5
Signif. if > +-1	0.0	-0.3	0.3

Results from IACP Boise source lab study

```
"YATES" table for fuel, altitude and burnrate for
TOTAL GC/MS PAH

 FIRST    SECOND  DIFFERENCE   MEAN
 VALUE    VALUE                VALUE       1          2          3

 44565.8  63284.7   -18718.9  53925.2   53925.2  142881.4  328190.3   Total
     0.0      0.0        0.0      0.0   88956.2  185308.8**********     A
 37976.9 108048.4   -70071.6  73012.7   64577.7**********   91184.4     C
  9366.6  22520.4   -13153.8  15943.5  120731.1********** -15141.2    AC
 69054.8  51247.2    17807.6  60151.0  -53925.2   35031.0   42427.4     D
  4426.7   4426.7        0.0   4426.7  -57069.1   56153.4  -12451.6    AD
 94226.4  94226.4        0.0  94226.4  -55724.4   -3143.9   21122.5    CD
 36143.4  16866.1    19277.3  26504.8  -67721.6  -11997.2   -8853.3   ACD


                         A          AC        C          D         AD        CD
                        Fuel                Altitude    Rate
Main Effects          -58610.1   -3785.3   22796.1   10606.9   -3112.9    5280.6
Error Variance      612216549.8
Variance of Mean    306108274.9
Stand. Deviation        17496.0
(Signif. if > +-1)
@90%CB,                   -2.3      -0.1       0.9       0.4      -0.1       0.2
@95%CB,                   -1.7      -0.1       0.6       0.3      -0.1       0.1
@99%CB,                   -1.0      -0.1       0.4       0.2      -0.1       0.1
```

```
"YATES" table for stove and rate for
TOTAL GC/MS PAH

 MEAN
 VALUE       1          2

 28263.5   82188.7   187512.8   Total
 53925.2  105324.1    40639.7     B
 45173.1   25661.7    23135.4     D
 60151.0   14978.0   -10683.8    BD


                          B          D         BD
                        Stove       Rate
Main Effects            20319.8   11567.7   -5341.9
Error Variance      612216549.8
Variance of Mean    459162412.4
Stand. Deviation        24743.0

Signif. if > +-1            0.6       0.3      -0.1
Signif. if > +-1            0.4       0.2      -0.1
Signif. if > +-1            0.2       0.1      -0.1
```

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for NAPHTHALENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
79.1	319.8	-240.8	199.4	199.4	587.8	2262.0	Total
0.0	0.0	0.0	0.0	388.4	1674.2	-1467.1	A
189.5	438.4	-248.9	314.0	596.2	-439.0	670.8	C
58.1	90.8	-32.7	74.4	1078.0	-1028.2	-284.4	AC
588.4	399.7	188.6	494.0	-199.4	188.9	1086.3	D
102.1	102.1	0.0	102.1	-239.5	481.8	-589.2	AD
857.1	857.1	0.0	857.1	-391.9	-40.1	292.9	CD
297.4	144.3	153.1	220.9	-636.3	-244.3	-204.3	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-366.8	-71.1	167.7	271.6	-147.3	73.2
Error Variance	18003.2					
Variance of Mean	9001.6					
Stand. Deviation	94.9					
(Signif. if > +-1)						
@90%CB,	-2.6	-0.5	1.2	1.9	-1.1	0.5
@95%CB,	-1.9	-0.4	0.9	1.4	-0.8	0.4
@99%CB,	-1.1	-0.2	0.5	0.9	-0.5	0.2

"YATES" table for stove and rate for NAPHTHALENE

MEAN VALUE	1	2	
130.6	330.0	1136.9	Total
199.4	806.9	250.1	B
312.8	68.8	476.8	D
494.0	181.2	112.4	BD

	B Stove	D Rate	BD
Main Effects	125.0	238.4	56.2
Error Variance	18003.2		
Variance of Mean	13502.4		
Stand. Deviation	134.2		
Signif. if > +-1	0.6	1.2	0.3
Signif. if > +-1	0.5	0.9	0.2
Signif. if > +-1	0.3	0.5	0.1

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for FLUORENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
19.9	26.5	-6.6	23.2	56.0	87.9	206.3	Total
32.9	32.9	0.0	32.9	31.9	118.3	-81.1	A
9.0	29.1	-20.1	19.1	34.3	3.4	25.7	C
9.5	16.1	-6.6	12.8	84.1	-84.5	-31.9	AC
41.5	27.0	14.5	34.3	9.7	-24.1	30.4	D
0.0	0.0	0.0	0.0	-6.3	49.8	-87.9	AD
67.1	67.1	0.0	67.1	-34.3	-15.9	73.9	CD
21.3	12.6	8.7	16.9	-50.2	-15.9	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-20.3	-8.0	6.4	7.6	-22.0	18.5
Error Variance	78.0					
Variance of Mean	39.0					
Stand. Deviation	6.2					
(Signif. if > +-1)						
@90%CB,	-2.2	-0.9	0.7	0.8	-2.4	2.0
@95%CB,	-1.6	-0.6	0.5	0.6	-1.7	1.5
@99%CB,	-1.0	-0.4	0.3	0.4	-1.0	0.9

"YATES" table for stove and rate for FLUORENE

MEAN VALUE	1	2	
9.5	32.6	75.2	Total
23.2	42.6	39.7	B
8.3	13.7	9.9	D
34.3	26.0	12.3	BD

	B Stove	D Rate	BD
Main Effects	19.8	5.0	6.1
Error Variance	78.0		
Variance of Mean	58.5		
Stand. Deviation	8.8		
Signif. if > +-1	1.5	0.4	0.5
Signif. if > +-1	1.1	0.3	0.3
Signif. if > +-1	0.7	0.2	0.2

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for PHENANTHRENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
40.4	122.7	-82.2	81.5	302.6	393.8	859.4	Total
221.1	221.1	0.0	221.1	91.2	465.5	-275.5	A
29.5	106.8	-77.2	68.2	92.6	94.4	68.8	C
20.2	25.9	-5.8	23.1	372.9	-369.9	-369.2	AC
114.2	71.1	43.2	92.6	139.5	-211.4	71.7	D
0.0	0.0	0.0	0.0	-45.1	280.2	-464.3	AD
325.1	325.1	0.0	325.1	-92.6	-184.6	491.6	CD
66.5	29.1	37.4	47.8	-277.3	-184.6	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-68.9	-92.3	17.2	17.9	-116.1	122.9
Error Variance	1602.6					
Variance of Mean	801.3					
Stand. Deviation	28.3					
(Signif. if > +-1)						
@90%CB,	-1.6	-2.2	0.4	0.4	-2.8	2.9
@95%CB,	-1.2	-1.6	0.3	0.3	-2.0	2.2
@99%CB,	-0.7	-1.0	0.2	0.2	-1.2	1.3

"YATES" table for stove and rate for PHENANTHRENE

MEAN VALUE	1	2	
32.4	113.9	278.3	Total
81.5	164.4	70.1	B
71.7	49.2	50.5	D
92.6	20.9	-28.3	BD

	B Stove	D Rate	BD
Main Effects	35.1	25.2	-14.1
Error Variance	1602.6		
Variance of Mean	1202.0		
Stand. Deviation	40.0		
Signif. if > +-1	0.6	0.4	-0.2
Signif. if > +-1	0.4	[illegible]	-0.2
Signif. if > +-1	0.3	[illegible]	-0.1

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for FLUORANTHENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
8.2	34.1	-25.9	21.1	81.3	102.3	233.9	Total
60.2	60.2	0.0	60.2	21.0	131.6	-73.2	A
8.5	23.8	-15.4	16.1	25.3	27.8	20.7	C
5.1	4.7	0.4	4.9	106.3	-100.9	-100.5	AC
28.2	22.5	5.8	25.3	39.0	-60.2	29.3	D
0.0	0.0	0.0	0.0	-11.2	80.9	-128.7	AD
90.9	90.9	0.0	90.9	-25.3	-50.3	141.2	CD
20.9	9.8	11.1	15.3	-75.6	-50.3	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-18.3	-25.1	5.2	7.3	-32.2	35.3
Error Variance	106.3					
Variance of Mean	53.2					
Stand. Deviation	7.3					
(Signif. if > +-1)						
@90%CB,	-1.7	-2.3	0.5	0.7	-3.0	3.3
@95%CB,	-1.2	-1.7	0.4	0.5	-2.2	2.4
@99%CB,	-0.7	-1.0	0.2	0.3	-1.3	1.4

"YATES" table for stove and rate for FLUORANTHENE

MEAN VALUE	1	2	
7.5	28.7	71.0	Total
21.1	42.3	22.0	B
17.0	13.6	13.7	D
25.3	8.4	-5.2	BD

	B Stove	D Rate	BD
Main Effects	11.0	6.8	-2.6
Error Variance	106.3		
Variance of Mean	79.7		
Stand. Deviation	10.3		
Signif. if > +-1	0.7	0.4	-0.2
Signif. if > +-1	0.5	0.3	-0.1
Signif. if > +-1	0.3	0.2	-0.1

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
PYRENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
13.6	33.4	-19.8	23.5	108.4	132.4	283.5	Total
84.9	84.9	0.0	84.9	24.0	151.1	-65.7	A
11.4	25.5	-14.1	18.4	19.9	48.5	26.8	C
5.1	5.9	-0.8	5.5	131.2	-114.3	-148.7	AC
22.5	17.3	5.2	19.9	61.5	-84.4	18.7	D
0.0	0.0	0.0	0.0	-12.9	111.2	-162.8	AD
112.7	112.7	0.0	112.7	-19.9	-74.4	195.7	CD
27.7	9.1	18.6	18.4	-94.3	-74.4	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-16.4	-37.2	6.7	4.7	-40.7	48.9
Error Variance	96.4					
Variance of Mean	48.2					
Stand. Deviation	6.9					
(Signif. if > +-1)						
@90%CB,	-1.6	-3.6	0.7	0.5	-4.0	4.8
@95%CB,	-1.2	-2.7	0.5	0.3	-2.9	3.5
@99%CB,	-0.7	-1.6	0.3	0.2	-1.7	2.1

"YATES" table for stove and rate for
PYRENE

MEAN VALUE	1	2	
7.2	30.7	68.7	Total
23.5	38.0	18.2	B
18.0	16.2	7.2	D
19.9	1.9	-14.3	BD

	B Stove	D Rate	BD
Main Effects	9.1	3.6	-7.2
Error Variance	96.4		
Variance of Mean	72.3		
Stand. Deviation	9.8		
Signif. if > +-1	0.6	0.2	-0.5
Signif. if > +-1	0.5	0.2	-0.4
Signif. if > +-1	0.3	0.1	-0.2

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for BENZO(b)FLUORANTHE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
15.3	7.0	8.3	11.2	29.7	36.0	64.0	Total
18.5	18.5	0.0	18.5	6.4	28.0	-21.3	A
1.9	10.0	-8.1	6.0	5.1	1.8	-5.6	C
0.0	0.8	-0.8	0.4	22.9	-23.1	-25.8	AC
6.0	4.2	1.9	5.1	7.3	-23.3	-8.1	D
0.0	0.0	0.0	0.0	-5.5	17.7	-24.9	AD
20.4	20.4	0.0	20.4	-5.1	-12.9	41.0	CD
3.6	1.2	2.4	2.4	-18.0	-12.9	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-5.3	-6.4	-1.4	-2.0	-6.2	10.3
Error Variance	14.5					
Variance of Mean	7.2					
Stand. Deviation	2.7					
(Signif. if > +-1)						
@90%CB,	-1.3	-1.6	-0.3	-0.5	-1.6	2.6
@95%CB,	-1.0	-1.2	-0.3	-0.4	-1.1	1.9
@99%CB,	-0.6	-0.7	-0.2	-0.2	-0.7	1.1

"YATES" table for stove and rate for BENZO(b)FLUORANTHE

MEAN VALUE	1	2	
0.9	12.1	21.6	Total
11.2	9.5	10.9	B
4.4	10.2	-2.6	D
5.1	0.7	-9.5	BD

	B Stove	D Rate	BD
Main Effects	5.5	-1.3	-4.8
Error Variance	14.5		
Variance of Mean	10.9		
Stand. Deviation	3.8		
Signif. if > +-1	1.0	-0.2	-0.8
Signif. if > +-1	0.7	-0.2	-0.6
Signif. if > +-1	0.4	-0.1	-0.4

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for BENZO(k)FLUORANTHE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
1.1	2.7	-1.6	1.9	6.9	8.2	17.4	Total
5.1	5.1	0.0	5.1	1.2	9.2	-4.6	A
0.7	1.1	-0.4	0.9	1.7	2.7	0.0	C
0.4	0.3	0.0	0.3	7.5	-7.2	-7.5	AC
2.0	1.5	0.5	1.7	3.2	-5.7	1.1	D
0.0	0.0	0.0	0.0	-0.5	5.8	-9.9	AD
6.5	6.5	0.0	6.5	-1.7	-3.8	11.5	CD
1.5	0.5	1.0	1.0	-5.5	-3.8	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-1.1	-1.9	0.0	0.3	-2.5	2.9
Error Variance	0.4					
Variance of Mean	0.2					
Stand. Deviation	0.5					
(Signif. if > +-1)						
@90%CB,	-1.7	-2.8	0.0	0.4	-3.7	4.3
@95%CB,	-1.3	-2.1	0.0	0.3	-2.7	3.2
@99%CB,	-0.8	-1.2	0.0	0.2	-1.6	1.9

"YATES" table for stove and rate for BENZO(k)FLUORANTHE

MEAN VALUE	1	2	
0.3	2.2	5.2	Total
1.9	3.0	2.0	B
1.3	1.5	0.8	D
1.7	0.4	-1.1	BD

	B Stove	D Rate	BD
Main Effects	1.0	0.4	-0.6
Error Variance	0.4		
Variance of Mean	0.3		
Stand. Deviation	0.6		
Signif. if > +-1	1.1	0.4	-0.6
Signif. if > +-1	0.8	0.3	-0.4
Signif. if > +-1	0.5	0.2	-0.3

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for BENZO(a)PYRENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
1.7	7.7	-6.0	4.7	18.0	21.7	44.9	Total
13.3	13.3	0.0	13.3	3.7	23.2	-10.9	A
1.8	3.7	-2.0	2.8	3.6	6.8	1.7	C
0.8	1.1	-0.2	0.9	19.6	-17.6	-20.8	AC
4.2	3.0	1.2	3.6	8.6	-14.3	1.5	D
0.0	0.0	0.0	0.0	-1.8	15.9	-24.4	AD
16.8	16.8	0.0	16.8	-3.6	-10.4	30.2	CD
4.6	0.9	3.7	2.8	-14.0	-10.4	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-2.7	-5.2	0.4	0.4	-6.1	7.6
Error Variance	5.5					
Variance of Mean	2.7					
Stand. Deviation	1.7					
(Signif. if > +-1)						
@90%CB,	-1.1	-2.1	0.2	0.1	-2.5	3.1
@95%CB,	-0.8	-1.6	0.1	0.1	-1.8	2.3
@99%CB,	-0.5	-0.9	0.1	0.1	-1.1	1.4

"YATES" table for stove and rate for BENZO(a)PYRENE

MEAN VALUE	1	2	
0.8	5.5	12.0	Total
4.7	6.4	4.7	B
2.8	3.9	0.9	D
3.6	0.8	-3.1	BD

	B Stove	D Rate	BD
Main Effects	2.3	0.4	-1.5
Error Variance	5.5		
Variance of Mean	4.1		
Stand. Deviation	2.3		
Signif. if > +-1	0.7	0.1	-0.4
Signif. if > +-1	0.5	0.1	-0.3
Signif. if > +-1	0.3	0.1	-0.2

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for BENZO(g,h,i)PERYLE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	4.2	-4.2	2.1	2.1	7.3	42.4	Total
0.0	0.0	0.0	0.0	5.3	35.1	-17.7	A
1.1	8.8	-7.7	5.0	14.1	-6.7	10.0	C
0.0	0.6	-0.6	0.3	21.0	-11.0	-25.0	AC
5.1	3.3	1.8	4.2	-2.1	3.2	27.8	D
9.9	9.9	0.0	9.9	-4.7	6.8	-4.2	AD
18.8	18.8	0.0	18.8	5.7	-2.6	3.7	CD
2.7	1.5	1.2	2.1	-16.7	-22.4	-19.9	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-4.4	-6.3	2.5	6.9	-1.1	0.9
Error Variance	8.1					
Variance of Mean	4.0					
Stand. Deviation	2.0					
(Signif. if > +-1)						
@90%CB,	-1.5	-2.1	0.8	2.3	-0.4	0.3
@95%CB,	-1.1	-1.5	0.6	1.7	-0.3	0.2
@99%CB,	-0.7	-0.9	0.4	1.0	-0.2	0.1

"YATES" table for stove and rate for BENZO(g,h,i)PERYLE

MEAN VALUE	1	2	
1.7	3.8	10.1	Total
2.1	6.3	2.5	B
2.1	0.4	2.5	D
4.2	2.1	1.7	BD

	B Stove	D Rate	BD
Main Effects	1.2	1.3	0.9
Error Variance	8.1		
Variance of Mean	6.1		
Stand. Deviation	2.8		
Signif. if > +-1	0.3	0.3	0.2
Signif. if > +-1	0.2	0.2	0.1
Signif. if > +-1	0.1	0.1	0.1

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for DIBENZO(a,h)ANTHRA

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	1.0	-1.0	0.5	4.4	4.7	11.2	Total
3.9	3.9	0.0	3.9	0.3	6.5	-1.8	A
0.2	0.1	0.1	0.2	0.8	3.3	0.7	C
0.0	0.3	-0.3	0.1	5.6	-5.1	-6.8	AC
1.2	0.5	0.7	0.8	3.3	-4.1	1.7	D
0.0	0.0	0.0	0.0	-0.0	4.8	-8.4	AD
4.9	4.9	0.0	4.9	-0.8	-3.4	8.8	CD
1.3	0.1	1.2	0.7	-4.2	-3.4	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-0.4	-1.7	0.2	0.4	-2.1	2.2
Error Variance	0.3					
Variance of Mean	0.1					
Stand. Deviation	0.4					
(Signif. if > +-1)						
@90%CB,	-0.8	-3.0	0.3	0.8	-3.7	3.9
@95%CB,	-0.6	-2.2	0.2	0.6	-2.7	2.8
@99%CB,	-0.3	-1.3	0.1	0.3	-1.6	1.7

"YATES" table for stove and rate for DIBENZO(a,h)ANTHRA

MEAN VALUE	1	2	
0.8	1.3	2.3	Total
0.5	1.0	0.5	B
0.1	-0.3	-0.4	D
0.8	0.7	1.0	BD

	B Stove	D Rate	BD
Main Effects	0.2	-0.2	0.5
Error Variance	0.3		
Variance of Mean	0.2		
Stand. Deviation	0.5		
Signif. if > +-1	0.3	-0.2	0.6
Signif. if > +-1	0.2	-0.2	0.5
Signif. if > +-1	0.1	-0.1	0.3

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
TOTAL GC/MS PAH

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
493.7	760.6	-266.9	627.1	977.6	2002.7	5530.9	Total
350.5	350.5	0.0	350.5	1025.1	3528.2	-3396.7	A
440.1	1149.9	-709.7	795.0	1133.5	-841.5	1308.8	C
143.9	316.2	-172.3	230.1	2394.8	-2555.2	-576.6	AC
1311.1	955.9	355.2	1133.5	-276.6	47.5	1525.6	D
0.0	0.0	0.0	0.0	-564.9	1261.3	-1713.8	AD
1908.3	1908.3	0.0	1908.3	-1133.5	-288.3	1213.9	CD
682.1	290.9	391.2	486.5	-1421.8	-288.3	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-849.2	-144.2	327.2	381.4	-428.4	303.5
Error Variance	88385.1					
Variance of Mean	44192.6					
Stand. Deviation	210.2					
(Signif. if > +-1)						
@90%CB,	-2.7	-0.5	1.1	1.2	-1.4	1.0
@95%CB,	-2.0	-0.3	0.8	0.9	-1.0	0.7
@99%CB,	-1.2	-0.2	0.5	0.5	-0.6	0.4

"YATES" table for stove and rate for
TOTAL GC/MS PAH

MEAN VALUE	1	2	
291.3	918.4	2656.4	Total
627.1	1738.1	864.7	B
604.6	335.8	819.7	D
1133.5	528.9	193.0	BD

	B Stove	D Rate	BD
Main Effects	432.4	409.9	96.5
Error Variance	88385.1		
Variance of Mean	66288.8		
Stand. Deviation	297.3		
Signif. if > +-1	1.0	0.9	0.2
Signif. if > +-1	0.7	0.7	0.2
Signif. if > +-1	0.4	0.4	0.1

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for PHENANTHRENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
34.3	75.3	-41.0	54.8	148.5	207.0	367.4	Total
93.7	93.7	0.0	93.7	58.5	160.4	-105.1	A
17.8	63.9	-46.1	40.9	29.3	15.7	11.8	C
15.0	20.3	-5.3	17.6	131.1	-120.8	-124.5	AC
35.9	22.6	13.3	29.3	39.0	-90.0	-46.6	D
0.0	0.0	0.0	0.0	-23.3	101.9	-136.5	AD
111.3	111.3	0.0	111.3	-29.3	-62.2	191.9	CD
25.7	13.9	11.8	19.8	-91.5	-62.2	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-26.3	-31.1	3.0	-11.6	-34.1	48.0
Error Variance	415.2					
Variance of Mean	207.6					
Stand. Deviation	14.4					
(Signif. if > +-1)						
@90%CB,	-1.2	-1.5	0.1	-0.5	-1.6	2.3
@95%CB,	-0.9	-1.1	0.1	-0.4	-1.2	1.7
@99%CB,	-0.5	-0.6	0.1	-0.2	-0.7	1.0

"YATES" table for stove and rate for PHENANTHRENE

MEAN VALUE	1	2	
24.3	79.1	145.3	Total
54.8	66.2	22.7	B
37.0	30.4	-12.8	D
29.3	-7.7	-38.1	BD

	B Stove	D Rate	BD
Main Effects	11.4	-6.4	-19.1
Error Variance	415.2		
Variance of Mean	311.4		
Stand. Deviation	20.4		
Signif. if > +-1	0.4	-0.2	-0.6
Signif. if > +-1	0.3	-0.2	-0.5
Signif. if > +-1	0.2	-0.1	-0.3

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for FLUORANTHENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
6.9	20.9	-14.0	13.9	38.7	52.1	97.6	Total
24.7	24.7	0.0	24.7	13.4	45.5	-27.9	A
5.1	14.3	-9.2	9.7	8.0	4.8	4.3	C
3.8	3.7	0.1	3.7	37.5	-32.8	-33.5	AC
8.9	7.2	1.7	8.0	10.8	-25.2	-6.5	D
0.0	0.0	0.0	0.0	-6.0	29.5	-37.6	AD
31.1	31.1	0.0	31.1	-8.0	-16.8	54.7	CD
8.1	4.7	3.4	6.4	-24.8	-16.8	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-7.0	-8.4	1.1	-1.6	-9.4	13.7
Error Variance	29.4					
Variance of Mean	14.7					
Stand. Deviation	3.8					
(Signif. if > +-1)						
@90%CB,	-1.2	-1.5	0.2	-0.3	-1.7	2.4
@95%CB,	-0.9	-1.1	0.1	-0.2	-1.2	1.8
@99%CB,	-0.5	-0.6	0.1	-0.1	-0.7	1.1

"YATES" table for stove and rate for FLUORANTHENE

MEAN VALUE	1	2	
5.7	19.6	36.3	Total
13.9	16.8	7.5	B
8.7	8.3	-2.8	D
8.0	-0.7	-9.0	BD

	B Stove	D Rate	BD
Main Effects	3.8	-1.4	-4.5
Error Variance	29.4		
Variance of Mean	22.0		
Stand. Deviation	5.4		
Signif. if > +-1	0.5	-0.2	-0.6
Signif. if > +-1	0.3	-0.1	-0.4
Signif. if > +-1	0.2	-0.1	-0.2

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
PYRENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
11.5	20.5	-8.9	16.0	49.9	65.2	117.6	Total
33.9	33.9	0.0	33.9	15.3	52.5	-26.3	A
6.9	15.3	-8.4	11.1	6.3	11.1	5.2	C
3.8	4.6	-0.9	4.2	46.1	-37.4	-49.5	AC
7.1	5.5	1.6	6.3	17.9	-34.6	-12.7	D
0.0	0.0	0.0	0.0	-6.8	39.8	-48.5	AD
38.6	38.6	0.0	38.6	-6.3	-24.8	74.5	CD
10.7	4.4	6.3	7.5	-31.1	-24.8	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-6.6	-12.4	1.3	-3.2	-12.1	18.6
Error Variance	19.4					
Variance of Mean	9.7					
Stand. Deviation	3.1					
(Signif. if > +-1)						
@90%CB,	-1.4	-2.7	0.3	-0.7	-2.6	4.0
@95%CB,	-1.0	-2.0	0.2	-0.5	-1.9	3.0
@99%CB,	-0.6	-1.2	0.1	-0.3	-1.2	1.8

"YATES" table for stove and rate for
PYRENE

MEAN VALUE	1	2	
5.4	21.4	37.0	Total
16.0	15.6	7.6	B
9.3	10.6	-5.8	D
6.3	-3.0	-13.5	BD

	B Stove	D Rate	BD
Main Effects	3.8	-2.9	-6.8
Error Variance	19.4		
Variance of Mean	14.6		
Stand. Deviation	4.4		
Signif. if > +-1	0.6	-0.4	-1.0
Signif. if > +-1	0.4	-0.3	-0.8
Signif. if > +-1	0.3	-0.2	-0.5

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
BENZO(k)FLUORANTHE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.9	1.6	-0.7	1.3	3.5	4.3	7.5	Total
2.3	2.3	0.0	2.3	0.8	3.2	-1.6	A
0.4	0.7	-0.3	0.5	0.5	0.7	-0.7	C
0.3	0.3	0.0	0.3	2.6	-2.4	-2.5	AC
0.6	0.5	0.2	0.5	1.0	-2.7	-1.1	D
0.0	0.0	0.0	[illegible]	-0.3	2.1	-3.1	AD
2.2	2.2	0.0	2.2	-0.5	-1.3	4.8	CD
0.6	0.2	0.3	0.4	-1.8	-1.3	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-0.4	-0.6	-0.2	-0.3	-0.8	1.2
Error Variance	0.1					
Variance of Mean	0.0					
Stand. Deviation	0.2					
(Signif. if > +-1)						
@90%CB,	-1.4	-2.2	-0.6	-1.0	-2.7	4.2
@95%CB,	-1.1	-1.6	-0.4	-0.7	-2.0	3.1
@99%CB,	-0.6	-1.0	-0.3	-0.4	-1.2	1.9

"YATES" table for stove and rate for
BENZO(k)FLUORANTHE

MEAN VALUE	1	2	
6.6	7.8	14.6	Total
1.3	6.7	-10.9	B
6.2	-5.3	-1.1	D
0.5	-5.6	-0.3	BD

	B Stove	D Rate	BD
Main Effects	-5.5	-0.6	-0.2
Error Variance	0.1		
Variance of Mean	0.1		
Stand. Deviation	0.3		
Signif. if > +-1	-13.5	-1.4	-0.4
Signif. if > +-1	-9.9	-1.0	-0.3
Signif. if > +-1	-5.9	-0.6	-0.2

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
BENZO(a)PYRENE

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
1.5	4.7	-3.2	3.1	8.7	11.1	19.1	Total
5.6	5.6	0.0	5.6	2.4	8.0	-4.2	A
1.1	2.2	-1.2	1.7	1.1	1.6	-0.6	C
0.6	0.8	-0.2	0.7	6.9	-5.8	-7.0	AC
1.3	1.0	0.4	1.1	2.6	-6.4	-3.1	D
0.0	0.0	0.0	0.0	-0.9	5.7	-7.4	AD
5.8	5.8	0.0	5.8	-1.1	-3.5	12.1	CD
1.8	0.4	1.3	1.1	-4.6	-3.5	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-1.0	-1.8	-0.2	-0.8	-1.8	3.0
Error Variance	1.4					
Variance of Mean	0.7					
Stand. Deviation	0.8					
(Signif. if > +-1)						
@90%CB,	-0.8	-1.4	-0.1	-0.6	-1.5	2.5
@95%CB,	-0.6	-1.0	-0.1	-0.5	-1.1	1.8
@99%CB,	-0.4	-0.6	-0.1	-0.3	-0.7	1.1

"YATES" table for stove and rate for
BENZO(a)PYRENE

MEAN VALUE	1	2	
6.6	9.7	17.0	Total
3.1	7.3	-8.5	B
6.2	-3.5	-2.4	D
1.1	-5.0	-1.5	BD

	B Stove	D Rate	BD
Main Effects	-4.3	-1.2	-0.8
Error Variance	1.4		
Variance of Mean	1.0		
Stand. Deviation	1.2		
Signif. if > +-1	-2.4	-0.7	-0.4
Signif. if > +-1	-1.8	-0.5	-0.3
Signif. if > +-1	-1.1	-0.3	-0.2

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for DIBENZO(a,h)ANTHRA

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	0.6	-0.6	0.3	1.8	2.0	4.2	Total
1.5	1.5	0.0	1.5	0.2	2.2	-0.5	A
0.1	0.1	0.1	0.1	0.3	1.1	0.1	C
0.0	0.2	-0.2	0.1	2.0	-1.7	-2.3	AC
0.4	0.2	0.2	0.3	1.2	-1.6	0.2	D
0.0	0.0	0.0	0.0	-0.0	1.7	-2.8	AD
1.7	1.7	0.0	1.7	-0.3	-1.2	3.3	CD
0.5	0.0	0.4	0.3	-1.4	-1.2	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-0.1	-0.6	0.0	0.1	-0.7	0.8
Error Variance	0.1					
Variance of Mean	0.0					
Stand. Deviation	0.2					
(Signif. if > +-1)						
@90%CB,	-0.5	-2.1	0.1	0.2	-2.6	2.9
@95%CB,	-0.4	-1.5	0.1	0.1	-1.9	2.2
@99%CB,	-0.2	-0.9	0.0	0.1	-1.1	1.3

"YATES" table for stove and rate for DIBENZO(a,h)ANTHRA

MEAN VALUE	1	2	
6.6	6.9	13.3	Total
0.3	6.4	-12.2	B
6.2	-6.3	-0.5	D
0.3	-5.9	0.4	BD

	B Stove	D Rate	BD
Main Effects	-6.1	-0.2	0.2
Error Variance	0.1		
Variance of Mean	0.1		
Stand. Deviation	0.3		
Signif. if > +-1	-15.6	-0.6	0.5
Signif. if > +-1	-11.4	-0.4	0.3
Signif. if > +-1	-6.8	-0.3	0.2

```
Results from IACP Boise source lab study

                     "YATES" table for fuel, altitude and burnrate for
                     K  POTASSIUM

 FIRST   SECOND  DIFFERENCE   MEAN
 VALUE   VALUE                VALUE      1        2        3

 2019.2   440.3    1578.9    1229.8   4502.9   8380.7  17949.6   Total
 3273.1  3273.1       0.0    3273.1   3877.9   9568.9   9589.7     A
  315.4  1519.1   -1203.7     917.3   5366.1   4086.7  -1788.3     C
 2385.4  3535.8   -1150.4    2960.6   4202.8   5503.0      0.0    AC
 1666.1   948.4     717.7    1307.3   2043.4   -625.0   1188.2     D
 4058.8  4058.8       0.0    4058.8   2043.4  -1163.3   1416.3    AD
  725.6   725.6       0.0     725.6   2751.5      0.0   -538.3    CD
 4153.3  2801.0    1352.4    3477.2   2751.5      0.0      0.0   ACD


                        A        AC       C         D        AD       CD
                       Fuel             Altitude   Rate
Main Effects          2397.4     0.0    -447.1    297.0    354.1   -134.6
Error Variance      760944.3
Variance of Mean    380472.1
Stand. Deviation       616.8
(Signif. if > +-1)
@90%CB,                  2.6     0.0      -0.5      0.3      0.4     -0.1
@95%CB,                  1.9     0.0      -0.4      0.2      0.3     -0.1
@99%CB,                  1.2     0.0      -0.2      0.1      0.2     -0.1
```

```
"YATES" table for stove and rate for
K  POTASSIUM

 MEAN
 VALUE      1          2

  341.9   1571.7     3449.8   Total
 1229.8   1878.1     1624.3     B
  570.8    887.8      306.4     D
 1307.3    736.5     -151.4    BD


                          B         D        BD
                        Stove      Rate
Main Effects             812.2    153.2    -75.7
Error Variance        760944.3
Variance of Mean      570708.2
Stand. Deviation         872.3

Signif. if > +-1           0.6      0.1     -0.1
Signif. if > +-1           0.5      0.1     -0.0
Signif. if > +-1           0.3      0.1     -0.0
```

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
Ni NICKEL

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	0.0	0.0	0.0	0.0	1.8	14.2	Total
0.0	0.0	0.0	0.0	1.8	12.4	-3.7	A
0.0	3.7	-3.7	1.8	5.3	-1.8	3.7	C
0.0	0.0	0.0	0.0	7.1	-1.8	-14.2	AC
0.0	0.0	0.0	0.0	0.0	1.8	10.6	D
5.3	5.3	0.0	5.3	-1.8	1.8	0.0	AD
7.1	7.1	0.0	7.1	5.3	-1.8	-0.0	CD
0.0	0.0	0.0	0.0	-7.1	-12.4	-10.6	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-0.9	-3.6	0.9	2.6	0.0	-0.0
Error Variance	1.4					
Variance of Mean	0.7					
Stand. Deviation	0.8					
(Signif. if > +-1)						
@90%CB,	-0.8	-2.9	0.8	2.2	0.0	-0.0
@95%CB,	-0.6	-2.1	0.6	1.6	0.0	-0.0
@99%CB,	-0.3	-1.3	0.3	1.0	0.0	-0.0

"YATES" table for stove and rate for
Ni NICKEL

MEAN VALUE	1	2	
0.0	0.0	0.0	Total
0.0	0.0	0.0	B
0.0	0.0	0.0	D
0.0	0.0	0.0	BD

	B Stove	D Rate	BD
Main Effects	0.0	0.0	0.0
Error Variance	1.4		
Variance of Mean	1.0		
Stand. Deviation	1.2		
Signif. if > +-1	0.0	0.0	0.0
Signif. if > +-1	0.0	0.0	0.0
Signif. if > +-1	0.0	0.0	0.0

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
Pb LEAD

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	0.0	0.0	0.0	5.0	10.0	21.8	Total
5.0	5.0	0.0	5.0	5.0	11.8	21.8	A
0.0	0.0	0.0	0.0	5.9	10.0	0.0	C
3.3	6.7	-3.3	5.0	5.9	11.8	0.0	AC
0.0	0.0	0.0	0.0	5.0	0.0	1.8	D
5.9	5.9	0.0	5.9	5.0	0.0	1.8	AD
0.0	0.0	0.0	0.0	5.9	0.0	0.0	CD
6.7	5.1	1.5	5.9	5.9	0.0	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	5.4	0.0	0.0	0.5	0.5	0.0
Error Variance	1.4					
Variance of Mean	0.7					
Stand. Deviation	0.8					
(Signif. if > +-1)						
@90%CB,	4.5	0.0	0.0	0.4	0.4	0.0
@95%CB,	3.3	0.0	0.0	0.3	0.3	0.0
@99%CB,	2.0	0.0	0.0	0.2	0.2	0.0

"YATES" table for stove and rate for
Pb LEAD

MEAN VALUE	1	2	
14.6	14.6	19.3	Total
0.0	4.7	-19.3	B
4.7	-14.6	-9.9	D
0.0	-4.7	9.9	BD

	B Stove	D Rate	BD
Main Effects	-9.7	-4.9	4.9
Error Variance	1.4		
Variance of Mean	1.0		
Stand. Deviation	1.2		
Signif. if > +-1	-5.6	-2.9	2.9
Signif. if > +-1	-4.1	-2.1	2.1
Signif. if > +-1	-2.5	-1.3	1.3

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
K POTASSIUM

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
22.4	5.3	17.1	13.8	60.9	114.0	290.0	Total
47.1	47.1	0.0	47.1	53.1	176.0	163.8	A
3.7	16.2	-12.5	9.9	98.0	66.5	-27.8	C
36.7	49.6	-13.0	43.2	78.0	97.3	-0.0	AC
31.6	17.7	13.9	24.7	33.2	-7.8	62.0	D
73.3	73.3	0.0	73.3	33.2	-19.9	30.8	AD
14.7	14.7	0.0	14.7	48.7	0.0	-12.1	CD
78.4	48.3	30.1	63.3	48.7	-0.0	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	40.9	-0.0	-6.9	15.5	7.7	-3.0
Error Variance	171.6					
Variance of Mean	85.8					
Stand. Deviation	9.3					
(Signif. if > +-1)						
@90%CB,	3.0	-0.0	-0.5	1.1	0.6	-0.2
@95%CB,	2.2	-0.0	-0.4	0.8	0.4	-0.2
@99%CB,	1.3	-0.0	-0.2	0.5	0.2	-0.1

"YATES" table for stove and rate for
K POTASSIUM

MEAN VALUE	1	2	
3.5	17.4	49.7	Total
13.8	32.3	27.3	B
7.6	10.3	14.9	D
24.7	17.0	6.7	BD

	B Stove	D Rate	BD
Main Effects	13.7	7.5	3.4
Error Variance	171.6		
Variance of Mean	128.7		
Stand. Deviation	13.1		
Signif. if > +-1	0.7	0.4	0.2
Signif. if > +-1	0.5	0.3	0.1
Signif. if > +-1	0.3	0.2	0.1

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
Ni NICKEL

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	0.0	0.0	0.0	0.0	0.0	0.3	Total
0.0	0.0	0.0	0.0	0.0	0.3	-0.0	A
0.0	0.0	-0.0	0.0	0.1	-0.0	0.0	C
0.0	0.0	0.0	0.0	0.1	-0.0	-0.3	AC
0.0	0.0	0.0	0.0	0.0	0.0	0.2	D
0.1	0.1	0.0	0.1	-0.0	0.0	0.0	AD
0.1	0.1	0.0	0.1	0.1	-0.0	-0.0	CD
0.0	0.0	0.0	0.0	-0.1	-0.3	-0.2	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	-0.0	-0.1	0.0	0.1	0.0	-0.0
Error Variance	0.0					
Variance of Mean	0.0					
Stand. Deviation	0.0					
(Signif. if > +-1)						
@90%CB,	-0.8	-5.6	0.8	4.8	0.0	-0.0
@95%CB,	-0.6	-4.1	0.6	3.5	0.0	-0.0
@99%CB,	-0.3	-2.4	0.3	2.1	0.0	-0.0

"YATES" table for stove and rate for
Ni NICKEL

MEAN VALUE	1	2	
0.0	0.0	0.0	Total
0.0	0.0	0.0	B
0.0	0.0	0.0	D
0.0	0.0	0.0	BD

	B Stove	D Rate	BD
Main Effects	0.0	0.0	0.0
Error Variance	0.0		
Variance of Mean	0.0		
Stand. Deviation	0.0		
Signif. if > +-1	0.0	0.0	0.0
Signif. if > +-1	0.0	0.0	0.0
Signif. if > +-1	0.0	0.0	0.0

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
Pb LEAD

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	0.0	0.0	0.0	0.1	0.1	0.4	Total
0.1	0.1	0.0	0.1	0.1	0.2	0.4	A
0.0	0.0	0.0	0.0	0.1	0.1	-0.0	C
0.1	0.1	-0.0	0.1	0.1	0.2	-0.0	AC
0.0	0.0	0.0	0.0	0.1	0.0	0.1	D
0.1	0.1	0.0	0.1	0.1	-0.0	0.1	AD
0.0	0.0	0.0	0.0	0.1	0.0	-0.0	CD
0.1	0.1	0.0	0.1	0.1	-0.0	-0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	0.1	-0.0	-0.0	0.0	0.0	-0.0
Error Variance	0.0					
Variance of Mean	0.0					
Stand. Deviation	0.0					
(Signif. if > +-1)						
@90%CB,	4.8	-0.0	-0.0	0.9	0.9	-0.0
@95%CB,	3.5	-0.0	-0.0	0.7	0.7	-0.0
@99%CB,	2.1	-0.0	-0.0	0.4	0.4	-0.0

"YATES" table for stove and rate for
Pb LEAD

MEAN VALUE	1	2	
0.2	0.2	0.2	Total
0.0	0.1	-0.2	B
0.1	-0.2	-0.1	D
0.0	-0.1	0.1	BD

	B Stove	D Rate	BD
Main Effects	-0.1	-0.0	0.0
Error Variance	0.0		
Variance of Mean	0.0		
Stand. Deviation	0.0		
Signif. if > +-1	-4.0	-1.7	1.7
Signif. if > +-1	-3.0	-1.2	1.2
Signif. if > +-1	-1.8	-0.7	0.7

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for
K POTASSIUM

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
19.0	3.2	15.7	11.1	49.2	88.1	157.1	Total
38.1	38.1	0.0	38.1	38.9	69.0	97.4	A
2.2	9.7	-7.5	5.9	37.2	54.1	-15.8	C
27.2	38.8	-11.6	33.0	31.7	43.3	0.0	AC
9.9	5.6	4.3	7.8	27.0	-10.3	-19.2	D
29.4	29.4	0.0	29.4	27.0	-5.5	-10.7	AD
5.0	5.0	0.0	5.0	21.7	0.0	4.8	CD
30.3	23.1	7.1	26.7	21.7	0.0	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	24.3	0.0	-4.0	-4.8	-2.7	1.2
Error Variance	50.8					
Variance of Mean	25.4					
Stand. Deviation	5.0					
(Signif. if > +-1)						
@90%CB,	3.3	0.0	-0.5	-0.6	-0.4	0.2
@95%CB,	2.4	0.0	-0.4	-0.5	-0.3	0.1
@99%CB,	1.4	0.0	-0.2	-0.3	-0.2	0.1

"YATES" table for stove and rate for
K POTASSIUM

MEAN VALUE	1	2	
2.6	13.7	25.5	Total
11.1	11.7	12.3	B
3.9	8.5	-2.0	D
7.8	3.9	-4.6	BD

	B Stove	D Rate	BD
Main Effects	6.2	-1.0	-2.3
Error Variance	50.8		
Variance of Mean	38.1		
Stand. Deviation	7.1		
Signif. if > +-1	0.6	-0.1	-0.2
Signif. if > +-1	0.4	-0.1	-0.2
Signif. if > +-1	0.3	-0.0	-0.1

Results from IACP Boise source lab study

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"YATES" table for fuel, altitude and burnrate for
Ni NICKEL

FIRST  SECOND  DIFFERENCE  MEAN
VALUE  VALUE               VALUE     1      2      3

 0.0    0.0      0.0        0.0     0.0    0.0    0.1   Total
 0.0    0.0      0.0        0.0     0.0    0.1   -0.0   A
 0.0    0.0     -0.0        0.0     0.0   -0.0    0.0   C
 0.0    0.0      0.0        0.0     0.0   -0.0   -0.1   AC
 0.0    0.0      0.0        0.0     0.0    0.0    0.1   D
 0.0    0.0      0.0        0.0    -0.0    0.0   -0.0   AD
 0.0    0.0      0.0        0.0     0.0   -0.0    0.0   CD
 0.0    0.0      0.0        0.0    -0.0   -0.1   -0.1   ACD

                       A       AC       C         D       AD      CD
                      Fuel           Altitude    Rate
Main Effects          -0.0    -0.0     0.0       0.0     -0.0     0.0
Error Variance         0.0
Variance of Mean       0.0
Stand. Deviation       0.0
(Signif. if > +-1)
@90%CB,               -0.8    -3.2     0.8       2.4     -0.0     0.0
@95%CB,               -0.6    -2.3     0.6       1.8     -0.0     0.0
@99%CB,               -0.3    -1.4     0.3       1.1     -0.0     0.0
```

```
"YATES" table for stove and rate for
Ni NICKEL

MEAN
VALUE     1       2

 0.0     0.0     0.0   Total
 0.0     0.0     0.0   B
 0.0     0.0     0.0   D
 0.0     0.0     0.0   BD

                         B        D       BD
                       Stove     Rate
Main Effects            0.0      0.0      0.0
Error Variance          0.0
Variance of Mean        0.0
Stand. Deviation        0.0

Signif. if > +-1        0.0      0.0      0.0
Signif. if > +-1        0.0      0.0      0.0
Signif. if > +-1        0.0      0.0      0.0
```

Results from IACP Boise source lab study

"YATES" table for fuel, altitude and burnrate for Pb LEAD

FIRST VALUE	SECOND VALUE	DIFFERENCE	MEAN VALUE	1	2	3	
0.0	0.0	0.0	0.0	0.1	0.1	0.2	Total
0.1	0.1	0.0	0.1	0.1	0.1	0.2	A
0.0	0.0	0.0	0.0	0.0	0.1	0.0	C
0.0	0.1	-0.0	0.1	0.0	0.1	0.0	AC
0.0	0.0	0.0	0.0	0.1	0.0	-0.0	D
0.0	0.0	0.0	0.0	0.1	0.0	-0.0	AD
0.0	0.0	0.0	0.0	0.0	0.0	0.0	CD
0.0	0.0	0.0	0.0	0.0	0.0	0.0	ACD

	A Fuel	AC	C Altitude	D Rate	AD	CD
Main Effects	0.1	0.0	0.0	-0.0	-0.0	0.0
Error Variance	0.0					
Variance of Mean	0.0					
Stand. Deviation	0.0					
(Signif. if > +-1)						
@90%CB,	4.3	0.0	0.0	-0.4	-0.4	0.0
@95%CB,	3.1	0.0	0.0	-0.3	-0.3	0.0
@99%CB,	1.9	0.0	0.0	-0.2	-0.2	0.0

"YATES" table for stove and rate for Pb LEAD

MEAN VALUE	1	2	
0.1	0.1	0.1	Total
0.0	0.0	-0.1	B
0.0	-0.1	-0.1	D
0.0	-0.0	0.1	BD

	B Stove	D Rate	BD
Main Effects	-0.1	-0.0	0.0
Error Variance	0.0		
Variance of Mean	0.0		
Stand. Deviation	0.0		
Signif. if > +-1	-4.4	-2.4	2.4
Signif. if > +-1	-3.2	-1.8	1.8
Signif. if > +-1	-1.9	-1.1	1.1